UNIVERSITY OF ILLINOIS
BULLETIN

Vol. 47 November, 1949 No. 23

ENGINEERING EXPERIMENT STATION
CIRCULAR SERIES No. 57

A SURVEY OF ELECTRICAL INSULATION PRACTICES

BY

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PRICE: SEVENTY CENTS

PUBLISHED BY THE UNIVERSITY OF ILLINOIS
URBANA

Published seven times each month by the University of Illinois. Entered as second-class matter December 11, 1912, at the post office at Urbana, Illinois, under the Act of August 24, 1912. Office of Publication, 358 Administration Building, Urbana, Illinois.

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3000—11-49—41470

UNIVERSITY
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CONTENTS

LIST OF CURVES

LIST OF CHARTS

Varnish Charts

Application Charts

Detailed Chart

(1) In envelope attached to inside back cover.

LIST OF TABLES

A SURVEY OF ELECTRICAL INSULATION PRACTICES

I. Introduction

Countless articles deal with specialized phases of electrical insulation. Most treat of a single insulating material or its combination with other materials. Because the tendency has been toward repetition and the presentation of test procedures and data, some of the articles have been hard to read and of little value to the ordinary engineer. In addition, many written by a person or small group connected with some commercial enterprise leave the reader rather confused as to the relative merits of the various types of insulation.

Of the many books on insulation, most are so theoretical that they are of little use to the engineer who desires to get a comprehensive yet practical background in a reasonably short time. (Noteworthy among those taking a more practical approach is D. P. Miner, *The Insulation of Electrical Apparatus.*)

The authors of this Circular have therefore tried to condense, and bring together in an unbiased manner the salient points of, a large number of articles, books, and other technical publications on insulation. They attempt to coordinate and compare various materials and their use in the light of present practices.

The user generally has a choice of several materials for a particular part of the insulation system. To assist readers to compare these materials, information on them is condensed and integrated by means of charts intended to facilitate selection of the best material for a given machine or transformer part.

To supplement data available in published form, it was necessary to get information from several of the larger electrical corporations. This help was graciously given, but with some qualifications because of the complexity and magnitude of the task involved in the formulation of charts. The major deficiencies of the data gathered are five.

1. The existence of hundreds of varnishes makes it hard to compare two or more varnished cloths. Thus, comparison between cotton impregnated with conventional varnish and silk, and a conventional varnish, has only limited value because their properties depend almost wholly on the type of varnish used with each.

2. The variations among the properties of a base material supplied by one manufacturer or a group are frequently greater than the variation between two different materials.

3. Comparison of the properties of insulating materials must

finally rest on laboratory test data. To simulate operating conditions, various companies have devised, for a particular property, a number of tests that yield different results.

4. The care and preparation of the varnish and the method of impregnation will alter the values of the various properties of a particular material.

5. The charts in this Circular do not completely cover all present types of insulating materials, since the data furnished dealt only with those types which were of particular interest to the cooperating manufacturers.

The presentation is qualitative, and stresses economics only in a general way. Though the economic principles may be fixed, yet the initial cost and the quality of an insulating material vary continuously, so that a detailed economic analysis is unfeasible.

The discussion is limited to insulating materials (both liquid and solid) as they are used in motors, generators, transformers, and associated parts. The discussion considers only those voltages and frequencies which are commonly used for power equipment. As a necessary reference for this discussion, the AIEE classification of insulating materials is included (Appendix A).

Chapter II presents the minimum amount of theory necessary as a background for Chapters III and IV. Functions and properties are discussed, indicating those properties essential for the proper performance of an insulation. Chapter III treats the properties, advantages, and disadvantages of the most widely used materials or groups of materials. Comparisons under unusual conditions of temperature and moisture are made between several of these materials. The information in Chapters II and III is utilized in Chapter IV to facilitate an inquiry into the desirable characteristics and design considerations of both rotating and nonrotating electrical apparatus.

Chapter V presents the authors' opinions of the trends in insulation. Although the authors have given much thought to the problem and have consulted many leaders in the field of electrical insulation, the chapter is a collection of opinions and should be so regarded.

Difficulties and confusion arise from the present classification of insulating materials. The advantage of rating a piece of electrical equipment on the basis of temperature rise alone has been questioned frequently. (See Chapter V.)

The sources of information used in preparing this Circular are of five kinds: technical journals and magazines, books, literature from 47 companies and other organizations, correspondence with insulation leaders, and survey trips to manufacturers and users.

Acknowledgment is gratefully made of the contributions of information by the following companies:

Acme Wire Co., New Haven, Conn.
Allis-Chalmers Manufacturing Co., Milwaukee, Wis.
Allis-Chalmers Manufacturing Co., Pittsburgh, Penn.
American Cyanamid Co., New York, N.Y.
Anaconda Wire and Cable Co., Muskegon, Mich.
Balder Electric Co., St. Louis, Mo.
Belden Mfg. Co., Chicago, Ill.
Bentley-Harris Mfg. Co., Conshohocken, Penn.
Brown Boveri Corp., New York, N.Y.
Connecticut Hard Rubber Co., New Haven, Conn.
Continental Diamond Fibre Co., Valparaiso, Ind.
Delco Products, Dayton, Ohio
Detroit Edison Co., Detroit, Mich.
Dow-Corning Corp., Midland, Mich.
Electro-Motive Diesel, LaGrange, Ill.
Formica Insulation Co., Cincinnati, Ohio
General Electric Corp., Schenectady, N.Y.
General Electric Co., Pittsfield, Mass.
Insulation Mfg. Corp., Chicago, Ill.
Irvington Varnish and Insulator Co., Irvington, N.J.
John A. Roebling's Sons Co., Trenton, N.J.
John C. Dolph Co., Newark, N.J.
Mica Insulator Co., Schenectady, N.Y.
Monsanto Chemical Co., Springfield, Mass.
National Electric Coil Co., Columbus, Ohio
National Vulcanized Fibre Co., Kennett Square, Penn.
National Varnished Products Corp., Woodbridge, N.J.
Navy Dept., Bureau of Ships, Washington, D.C.
N.R.M.A., New York, N.Y.
New Jersey Wood Finishing Co., Woodbridge, N.J.
Owens-Corning Fiberglas Corp., Toledo, Ohio
P. D. George Co., St. Louis, Mo.
Phelps-Dodge Copper Products Corp., Fort Wayne, Ind.
Progressive Welder Co., Detroit, Mich.
R. E. Uptegraff Mfg. Co., Scottdale, Penn.
Rome Cable Corp., Rome, N.Y.
Spaulding Fibre Co., Inc., Tonawanda, N.Y.
Standard Insulation Co., East Rutherford, N.J.
Standard Transformer Co., Warren, Ohio
Sterling Varnish Co., Haysville, Penn.
Suflex Corp., Woodside, N.Y.
Synvar Corp., Wilmington, Del.
Varvlex Corp., Rome, N.Y.
Wagner Electric Co., St. Louis, Mo.
Westinghouse Electric Corp., East Pittsburgh, Penn.

Further grateful acknowledgment is given of the invaluable preliminary investigation made by Fred R. Grisak, formerly Special Research Assistant at the University of Illinois, and the generous aid of Miss Hilda J. Alseth, Engineering Librarian.

II. Functions and Properties of Insulation

1. *Introduction*

A salient fact when specifying the insulation to be used with a particular type of equipment is that there exists no single insulating material which will do the necessary job. A combination of materials must be used; it may vary with every application, depending on the electrical, mechanical, chemical, and thermal conditions in the location where the machine is to be employed.

In other words, the insulation system for an apparatus should be tailored to fit the physical conditions and the application. The designer must consequently have a wide knowledge of many types of insulating materials, of their compatibility with each other, and of methods that enable him to compensate for the limitations of certain of these materials so that the machine will give satisfactory and dependable performance as a whole.

There is no single source of information on all types of insulating materials and the factors governing their selection and use. The designer must of necessity rely on information supplied by the manufacturer of insulations and may not get a clear picture of all the factors involved. This Circular therefore attempts to point out the functions of insulating materials, to discuss their advantages and limitations when applied to electrical apparatus, and to give an idea of which materials will give the best performance according to conditions under which they must operate.

2. *Functions, Electrical and Mechanical*

The primary function of insulation is to prevent current from flowing in other than the prescribed paths in the apparatus. If this is to be done it is necessary that there be a physical separation of the conductors. Hence, in order to accomplish its primary function an insulating material must perform another function that is largely mechanical. It is desirable to keep this separation small and yet provide sufficient resistivity and dielectric strength. For this reason combinations of materials are often used—cotton, rayon, silk, glass, etc.—impregnated with varnish. The cotton alone could provide the mechanical and electrical strength, but a large quantity of it would be necessary. In the combination the cloth acts as a spacer, providing mechanical strength and acting as a carrier for the varnish. It is the varnish, however, that provides the resistivity and dielectric strength required to keep the current in its prescribed path.

Electrical Functions.—Three factors enter into the consideration of a material as a dielectric: resistivity, dielectric strength, and dielectric loss. It is probable that dielectric strength would be considered the most important criterion in determining the value of a material as a dielectric—an emphasis that is justified because dielectric strength depends on many other factors, such as temperature, thermal aging, moisture, and mechanical wear.

The dielectric loss and the loss resulting from conductivity have no appreciable effect on the efficiency of the apparatus. Yet they are not to be neglected, since the heat from these losses may so raise the temperature of the insulation or a small part of the insulation that the dielectric strength becomes dangerously low. The losses increase the temperature of the insulation, increasing the losses—which further increases the temperature. A destructive cycle lending to breakdown of the insulation may thus be initiated.

Mechanical Functions.—Tremendous advances have been made in the improvement of old and in the discovery of newer and better insulating materials. Nevertheless these materials seldom have both excellent mechanical and electrical characteristics; usually one must be sacrificed to the other.

Briefly, it can be said that the insulating material must withstand compression, tension, flexing, and abrasion, because:

1) The space positions of the conductors relative to each other and to the rest of the machine must be maintained.

2) Paths must not be formed through which moisture, chemicals, etc., could enter the winding.

3) Voids must not be formed; for if the voltage gradient is high, corona may occur. The ozone and nitric oxide formed by corona may have destructive effects on the windings.

The major necessity for mechanical strength is that a serious deterioration of the mechanical properties will gradually lower the dielectric strength or else so condition the insulation as to make imminent an abrupt decrease of dielectric strength, which results in a breakdown.

It is clear that both electrical and mechanical functions are important. In the selection of an insulating material for a particular job both must be considered.

3. *Properties*

For insulating material to function satisfactorily, the following properties must be considered: 1) electrical properties, 2) mechanical strength, 3) thermal endurance, 4) chemical resistance, 5) moisture resistance, 6) aging. The degree to which these properties must be considered depends on the operating conditions of the apparatus. An accurate analysis of the properties of the available insulations is necessary in order to choose the material or the combination of materials to do the required task. Knowing the properties of these various materials, combinations to offset the limitations of an individual material can be made. The laboratory results cannot be used to predict accurately the effectiveness of the material in actual operation, but act merely as a guide. A careful consideration of the magnitude of each of the above properties, the duration of the operating cycle, and the effect they or a breakdown might have, is essential in providing an adequate insulating material for a particular piece of apparatus.

Electrical Properties.—The electrical characteristics required if an insulating material is to perform its electrical functions are well known for each type of apparatus. The choice and design of an insulation system which will initially meet the electrical requirements are not too difficult; the major problem is the choice of materials that will continue to have dielectric strength, high insulation resistance, and low dielectric loss over a reasonable length of time during which the insulation is subjected to electrical, thermal, and mechanical stresses.

The dielectric strength is the factor which determines whether a material is acting as an insulation. When breakdown occurs, the conduction current increases abruptly and the dielectric strength and resistivity become small. There is then a visible physical rupture of the insulation at the point or points of breakdown.

The power loss in a dielectric is proportional to the loss factor, which may be expressed as $K \cdot \tan B$, where K is the dielectric constant and B is the complement of the power factor angle Q.* Since the power factor is generally very low, the loss factor may be expressed as $K \cdot \cos \theta$, where $\cos \theta$ is the power factor. A consideration of dielectric loss and power factor is of greater importance with high-voltage apparatus than with low-voltage.

The insulation resistance of a machine gives an indication of the condition of the winding. A low insulation resistance suggests that the winding is not in proper condition—not necessarily that it is about to fail but that it has a high moisture content or is dirty and should be dried or cleaned. Neither does a high insulation resistance indicate beyond question that the winding is in good condition: it

* Beldi, Fr., "The Insulation of Machines and Transformers," *The Brown Boveri Review*, Sept.-Oct., 1943, pp. 224-34.

may have failed on the end turns and yet gives a high insulation resistance if clean and dry. The measurements of insulation resistance can be of considerable value, although only when properly interpreted.

A single measured value of insulation resistance has in itself little value. A correlation with a series of past measurements of that machine and of similar machines is essential. The insulation resistance varies inversely with the temperature and the moisture content of the insulation. Hence the magnitude of the insulation resistance depends on the season of the year during which the apparatus was built. Insulation resistance usually decreases as applied voltage increases. It varies also with the duration of the voltage application, increasing during the first few minutes. When the insulation resistance is to be measured, the ASA Standards should be followed.

Mechanical Strength.—The insulation must resist many mechanical stresses which occur during manufacture and operation, such as tensile, compressive, abrasive, and shearing stresses.

Manual as well as automatic winding processes may abrade the insulation so that it becomes more susceptible to moisture penetration or may decrease the effective thickness.

Differential expansion of the metals and the insulation during temperature changes results in tensile, compressive, and abrasive stresses. It is well known that there is a force on a current-carrying conductor which is in a magnetic field. In electrical apparatus these forces cause serious stresses. Under starting, overload, or short-circuit conditions those become very large and may damage the insulation, leading to failure then or later. Moreover, rotating equipment experiences large centrifugal forces that tend to throw the windings out of the slots of the rotating member.

Vibrations may cause movement of the conductors and hence wear of the insulation, particularly in rotating machines. Also, the surface of the insulating material should have sufficient strength to resist the abrasive action of dust particles in the ventilating air.

Of the tests ordinarily performed on electrical apparatus to determine mechanical aging, the tensile-strength most nearly represents the life of the equipment. Neither the dielectric strength nor the insulation resistance may be taken as an adequate criterion for determining the degree of mechanical aging.

Thermal Endurance.—The effects of temperature are usually considerations in connection with the deterioration of the insulation used on the various parts of the apparatus. However, many other parts are affected by temperature, and some even determine the maximum operating temperature. The effects can be grouped into two classes:

1) Effects of temperature on insulating parts and on parts other than insulation; and 2) Expansion and contraction of the various parts due to temperature changes.

The type of application will determine the frequency and the degree of overloads, factors important because the heating of windings during these overloads partly determines the life of the insulation. The overload capacity is greatly reduced when the full-load temperature rise is increased.*

If a given percentage of overload increases the temperature rise of a Class B insulated motor to twice its allowable rise, less damage would be done to it than if it were Class A insulation with the same percentage of overload.

The atmospheric conditions must also be considered in determining the type of insulation to be used. If the ambient temperature is high, one must take into account the reduced capacity of the frame to transmit heat. It may be necessary to use a larger motor or else better insulation—perhaps Class B or H instead of Class A. Tests have shown that the higher the temperature, the more rapid the deterioration due to any given condition; thus the shorter will be the life. It is known that the time required to cause cracking at any given radius of bend on a mandrel is shorter for a higher temperature. A gradual decrease in breakdown voltage occurs as the period of aging increases. Generally, up to 200 deg C (392 deg F) there is no critical temperature above which the insulation suddenly fails, but for each temperature there is a definite time required for the insulation to reach a given condition due to temperature aging. It can be said also that the lower the temperature the longer the life.

One of the first effects of heat is to drive off moisture. Continued application of heat may cause a chemical change in the molecules

* A good example is given by Alger and Jones:

"Assume, for example, that two similar motors in a 40 deg C (104 deg F) ambient temperature are compared at 1.25 times rated load, motor A having 60 deg C (140 deg F) rise and motor B, 120 deg C (248 deg F) rise at rated load, both motors having the same component losses at rated load. In each case, the copper losses at 1.25 load will be roughly 1.56 times the copper losses at rated load, since they vary as the square of the current. Since the temperature rise at overloads is nearly proportional to the copper loss, A will have an apparent temperature rise at 1.25 load of about 1.56 · 60, or 94 deg C (201 deg F), while B will have about 1.56 · 120 or 188 deg C (370 deg F) rise. With these increases in temperature, the copper resistance increases also, causing higher losses and still further rise of temperature. This causes the phenomenon of 'temperature creep' whereby the temperature goes on increasing for a long time after the application of the overload, in extreme cases becoming unstable and rising to destructive values. . . . The effects of temperature on lubricants, expansion, etc., also increase exponentially. . . .

"If a 10 deg C (50 deg F) rule for half life holds for the insulating materials in motor A, they will last only about four percent of the time at 1.25 load that they would last at rated load. Even if materials in motor B are much more heat resistant, and follow a 15 deg C (59 deg F) law for half life, this motor will still only last one-third percent as long as 1.25 load as at rated load." — "Rating of High Temperature Induction Motors," *Electrical Engineering*, 64:300-302, June, 1945.

in the organic material, or a change due to oxidation in the presence of the atmosphere (this might not occur in an inert medium). The oxidation by-products may cause further changes. Dimensional changes or the formation of voids in organic and semiorganic materials is generally the result of weight loss due to aging and heat deterioration. Not only do the resinous bonds between turns in a coil act as physical supports; they act also as thermal conductors. The weakest detail of an insulation determines when it fails. Any temperature above 100 deg C (212 deg F) has a negative effect whenever the insulation has absorbed moisture.

Chemical Resistance.—The presence of chemicals is due to many factors: those due to the manufacturing process (solder, varnish, binder, etc.), gaseous vapors in the atmosphere, liquid acids in nearby surroundings, the reaction of oil with oxygen to form acids, and the nitric acid and oxone which are formed by corona. There is a chemical change in the insulation due to thermal aging.

The use of inert gases to replace oxygen in the areas surrounding the oil and insulation in an enclosed medium is an effective means of minimizing the chemical change.

The various types of oils, lubricants, and insulating materials can be said to be resistant to a particular chemical in varying degrees. Silicones show the greatest resistance to chemicals. Chemicals introduced into the insulation during manufacture, repair, or service may be of the electrolytic type which reduce insulation resistance or dielectric breakdown strength of the insulation. In some cases a chemical harmless when at room temperature and dry will become conductive under high humidity conditions, particularly when hot.

Moisture Resistance.—Moisture is one of the main factors to be considered in insulation. It is desired to use a material that has the least moisture absorption and absorption qualities, because of the higher breakdown strength it will have. In some cases the difficulty that arises in the use of such a highly moisture-resistant material is that its "wetting" quality would be poor—i.e., the ability of a varnish to stick to it.

A Class B insulated coil has a greater resistance to moisture than a Class A, which depends solely on the ability of the varnish to resist moisture. Once the varnish is dried out and cracked, the structure of Class A materials is very conducive to moisture.

For a given external relative humidity condition, a Class B apparatus will have less moisture absorption during operation than a Class A type, because of the higher normal operating temperature.

While idle, moisture will be absorbed by either, depending on the characteristics of the insulating material.

As mentioned before, the insulation resistance is an indication of the condition of the insulation. One thing it can indicate is the moisture content of the insulation as compared to the value obtained when it is thoroughly dried out. A piece of equipment that has been in operation will generally have a much higher insulation resistance at ambient temperature than the same apparatus would have after a period of idleness in humid atmosphere. A low value of insulation resistance is not a true indication that the apparatus is unsafe for operation. If the value is high enough in comparison with periodic test data of the same piece of apparatus, the equipment can still be used. After it has been in operation for some time the temperature increase will dry the machine out and thus raise its insulation resistance.

Some insulating materials that are moisture-absorbing improve their breakdown strength under increases of temperature, as is especially noticeable when the surrounding air is dry and the moisture can be given up to it more readily.

Moisture in the insulation can act as a conductive path, and hence as a path for breakdown. The presence of moisture on the insulation may increase conduction losses and cause heating.

Aging.—"Aging" generally is used with reference to thermal aging—that is, the deterioration that results from exposure of the insulation to elevated temperatures. Aging is closely related to the properties mentioned previously in this chapter. Though essentially a diminution of these properties rather than a property itself, yet because it frequently is considered to be a property, it is separately discussed here.

Since aging is the decrease in mechanical strength, moisture resistance, etc., the degree of aging is measured in the laboratory by three kinds of tests:

1. Electrical
   a) Insulation resistance
   b) Electric breakdown
   c) Power factor
2. Mechanical
   a) Bending
   b) Flexibility
   c) Folding
   d) Tensile
   e) Abrasive
3. Visual

Laboratory measurements give an indication of the relative degrees of aging of various materials. These results should be applied with caution to the determination of the expected aging rate of the insulation for electrical equipment.

Attempts have been made to formulate a rule for determining quickly the effects of temperature on life. It is frequently assumed that if a given increase of temperature above a base temperature will reduce the life by half, a second temperature increment of the same magnitude will again reduce the life by half. If the equipment were operated continuously at the temperature corresponding to this second increment the expected life would be $\frac{1}{2} \cdot \frac{1}{2}$, or $\frac{1}{4}$ the life at the base. Unfortunately this simple rule does not hold for many materials. The second increment may decrease the expected life by more than $\frac{1}{2}$, perhaps by $\frac{2}{3}$, giving a life of $\frac{1}{2} \cdot \frac{1}{3}$, or $\frac{1}{6}$ instead of $\frac{1}{4}$.

The final test for the life of an insulation is the field test. Only by actual operation of a machine can the life of insulation be determined. Even then the operating conditions must be carefully specified so that extraneous factors do not invalidate the results.

III. INSULATING MATERIALS

4. *Introduction*

The functions and properties mentioned in the previous chapter could have been discussed under the heading of protection. The primary purposes of all insulation are electrical, mechanical, chemical, and moisture protection. The choice of the components of the insulation system of various types of electrical equipment depends on the degree of protection required. In each selection, that which will give the necessary safety factor, assure maximum life, and do the job at minimum expense is chosen.

There is available a great variety of insulating materials; this chapter is devoted mainly to those most widely used today.

A particular application will require an insulating material possessing certain properties. It is most probable that no single material will have all these properties to the required degree; so a combination of materials will be used. The materials supplement each other and can be so chosen that as a unit they will meet the specifications. Yet, because they act as a unit, the disadvantages of one of the materials may be present within the composite material. Consider an inorganic material reinforced with an organic to provide mechanical strength. The inorganic material used alone could resist high temperature; but the combination will not do so, because of the low temperature limit of the organic material.

The properties of certain solid and liquid insulating materials are first discussed, and some of them then compared.

5. *Solids*

Cellulose.—One of the most widely used groups of insulating materials is the cellulosic family, though its dielectric strength is substantially the same as that of air. It is used in many forms, such as cotton, paper, rayon, wood, and plastics, and most widely in the form of paper sheets or tapes and as a cotton spacer for insulation of conductors. The mechanical strength and economy of cellulose materials recommend them for an apparatus that is not to be subjected to unusual conditions of temperature and moisture. Since cellulose includes many types of insulating materials, its properties should be discussed in detail.

Tests have indicated that both untreated and treated cellulose undergo mechanical deterioration but retain their electrical characteristics, which may even improve when in the presence of inert gases up to 140 deg C (284 deg F). The mechanical deterioration of cellulose depends on the following factors: the presence of moisture and oxygen, the temperature that is applied to it, and the exposure to acidity. All have an effect.

The mechanical stability of cellulose insulation is even greatly affected by the presence of small amounts of moisture. An increase of the moisture content constituting 0.5 percent of the dry weight of the insulation will reduce the mechanical life tremendously. In general, for each doubling in water content of the insulation, its mechanical life is reduced by one-half. For practically dry insulation the approximate rate of deterioration above 120 deg C (248 deg F) depends on the history of the material. Another important effect of moisture is the expansion and contraction of the fibers during intermittent duty, resulting in the formation of voids and movement of conductors on rotating pieces of equipment.

From experimental data it has been determined that below approximately 120 deg C (248 deg F) oxygen has the greatest effect on the deterioration and that the presence of moisture accelerates this effect. From the same tests it has been found that cellulose when heated passes through a fixed period during which its mechanical characteristics are preserved and whose duration is shortened by the presence of oxygen.

Pyrochemical decomposition occurs at higher temperatures (about 120 deg C and upward). During the in-between stage the effect of oxidation merges into the effects produced by the pyrochemical decomposition. The hydroxyl groups in the cellulose molecules under severe temperatures may be split off as water. This effect hastens the deterioration of the insulation.

Upon oxidation of the cellulose, acids will be formed which, though weak, will nevertheless act as a catalyst for further decomposition. If the cellulose is placed in an inert atmosphere, acids will not be formed at temperatures of less than approximately 120 deg C.

The major consideration is that the rate of deterioration of the mechanical strength of cellulose increases with the increasing temperature of exposure. Even in the absence of oxygen it will undergo deterioration.

Plain cellulose insulation deteriorates faster than the same insulation treated and immersed in oil. This is true for temperatures in which severe oxidation or pyrochemical reactions are possible. In the presence of air and at elevated temperatures, oil will react in such a way that acids will be formed which will attack the cellulose.

Where relatively low electric stresses exist, cellulose can be used mainly as a spacer for the separation of adjacent conductors. It has been seen that chemical deterioration will result in the loss of dielectric efficiency and mechanical strength; it is therefore of prime importance that it be eliminated or carefully controlled.

Inasmuch as cotton, paper, rayon, etc., are basically cellulose materials, most of the foregoing discussion of the properties of cellulose will apply. The extent of this applicability depends upon the inherent characteristics of these materials.

(a) Cotton Chemically, cotton is nearly pure cellulose and is amenable to various treatments which add dielectric strength, moisture resistance, and resistivity to its original high mechanical strength.

The dielectric strength of unimpregnated cotton textiles as they come from the loom is largely determined by such factors as atmospheric conditions and surface contamination. As will be seen (Section 7), in a series of tests cotton showed the highest percentage of moisture by weight in comparison with asbestos and glass. Cotton alone is used in very special cases where the dielectric strength requirement is so low that the plain cotton will suffice—for example, as conductor insulation in oil-filled transformers. When used alone it must be used under such conditions that its low resistance to moisture will not prove detrimental.

In its main application, cotton can be considered a mechanical spacer and a carrier for the impregnant. Its chief use is for varnish-impregnated cloth and tape and as the filler in laminated plastics.

(b) Paper Paper is chemically inert in its purest form and of low inherent electrical conductivity. It lends itself surprisingly well to various types of electrical insulation, and there are over 100 different kinds that can be used. Its insulating properties are seriously lowered because of its physical structure. It normally contains much air and absorbed moisture. Untreated paper is little better than so much air. Like cotton, it is used as a carrier for insulating varnishes. It is hard, thin, dense, and inexpensive. In comparison to cotton, some of its mechanical properties are inferior. Below is a table listing the more important types of papers and their outstanding properties.

Type	*Derivative of*	*Properties*
Rag	Cotton rags	Tough, high abrasion resistance
Fish	Cotton	Dense, hard, tough, withstands sharp bending, unaffected by oil, dielectric strength is good when dry
Pressboard	Cotton, wood or a mixture	Porous, tough, easy to dry, amenable to oil impregnation
Kraft	Sulphate wood-pulp product	Ease of impregnation, strong, high dielectric strength and low power factor for .0004-in. tissue
Rope	Old hemp or hemp fiber	Stronger than cotton paper, tough, thin, amenable to impregnation
Jap	Mulberry fiber	Unusual strength due to long fibers

(c) Rayon A chemical derivative of cellulose, rayon has the same electrical properties as other cellulose products. Its outstanding features are its ability to allow the penetration of varnish and resinous materials and the smooth surface it has after impregnation. Rayon is as good as silk, and even better when aged in air. It has a lower tensile strength and abrasion resistance than wood or cotton (from which it is chemically derived).

(d) Wood Wood is gradually disappearing as an insulating material. Its chief use at the present time is as slot wedges. Materials have been found to replace it which have better electrical and mechanical properties.

(e) Synthetics Thermoplastics include certain cellulose materials which are important in the electrical insulating field. Although an attempt will be made here to list some of these which are cellulose derivatives, the discussion of plastics in general will be reserved for a later section.

Material	*Properties*
Cellulose Acetates	High dielectric strength; low moisture content; inflammable; to be used below 110 deg C (230 deg F); brittle and weak mechanically alone, but with a plasticizer in it, the fibers improve its mechanical strength. Will not corrode copper if corrosive lubricants are not used
Cotopa	A different form of cellulose acetate; low moisture content, greater mechanical strength than cellulose acetate, inflammable; to be used below 100 deg C (230 deg F); will not corrode copper if corrosive lubricants are not used
Ethyl Cellulose	Tough, flexible, maximum temperature for continuous use is about 105 deg C (221 deg F)

Glass.—One of the more recent developments in the inorganic field of insulation is glass. The pure glass fibers differ slightly in composition from ordinary glass in that they are alkali-free. Alkali would leach to the surfaces of the fibers. In the presence of moisture the result would be an ionizable salt which would decrease the insulation resistance. Glass is widely used as a Class B and Class H material because it is very resistant to high temperature, high humidity, and chemical action.

Two basic types of fiber are available—the staple fiber and the continuous filament, each having different applications. Staple fibers are approximately 9 in. long and form a tough material when woven, whereas the continuous filaments are very long and provide a smooth, silky appearance and great tensile strength. Cloth made with staple fibers has an appearance similar to cotton or woolen fabrics, and is to be preferred for heavy insulation where the space factor is not important and where a resilient material is desired. Fabrics woven with continuous filaments are more widely used because they have greater strength, permit a higher space factor, and present a better appearance than the staple fabrics. Glass in textile form has a high rate of heat conduction; in the wool form, a low rate.

The dielectric strength of unimpregnated glass is essentially the same as that of an equivalent thickness of air, depending somewhat on the humidity and the degree to which the surface has been contaminated. When impregnated, its dielectric strength rises to high values, depending upon the type of impregnant as well as the thoroughness of the impregnating and curing processes. If the humidity is high, glass takes on considerable moisture during periods of idleness, suffering a greatly reduced dielectric strength. When operated again, however, the moisture is driven off, with a resulting return of dielectric strength. The fibers themselves are nonhygroscopic, but moisture will collect on their surfaces. The insulation resistance is very high when dry, and though it decreases with increasing humidity it is not seriously reduced.

Over a large range of temperatures glass has a much higher tensile strength than comparable materials. It is little affected by temperatures up to 400 deg C (752 deg F).

Its low abrasion resistance and low shearing strength were initially causes of great concern, but the addition of lubricant and proper impregnation will almost completely eliminate this problem. Glass is resistant to abrasion by other materials, but glass will cut glass. The untreated fibers tend to cut and nick each other, making a thorough impregnation advisable. To increase the abrasion resistance of the finished glass product a lubricant is applied during manufacture, but in the apparatus this must be supplemented by varnish or other impregnants. When the lubricant or impregnant is eliminated or its qualities destroyed, vibration is apt to cause abrasive destruction. This limitation can be minimized by a thorough impregnation, followed by an adequate baking and curing process. Manufacturing experience indicates that little difficulty is experienced due to nicking and shearing during application or in obtaining a thorough impregnation, provided the proper varnish is used. Because of the inorganic nature of glass it is sometimes possible to speed up the baking and curing processes by using higher temperatures than conventional organic fabrics could withstand. The original lubricants were hygroscopic and corrosive to copper; however, progress has been made and will continue to be made in overcoming this difficulty as better lubricating materials are developed.

In much electrical apparatus, the necessary thickness of the insulation is determined by its required mechanical strength rather than by its electrical strength. Because of the high tensile strength of glass the thickness can be decreased and the space factor increased, thus reducing the size of the apparatus without a change in allowable temperature rise.

Glass is particularly suited for high temperature insulation, either Class B or Class H. The Class H 180 deg C (356 deg F) hot-spot temperature has but little effect upon the properties of the fiber itself. The limiting factors in this range of temperature are the characteristics of the impregnant and the mechanical properties of the parts of the apparatus other than insulation.

Glass insulation has distinct advantages, but it also has limitations. Its primary applications at the present time are those which require an exceptional resistance to heat, moisture and chemicals.

Asbestos.—Before refinement, asbestos, a bundle of external fine fibers, is contaminated by conducting salts. Chrysotile asbestos is the most useful type and the one most suited for electrical purposes. It can be applied to wire in a similar manner as the other materials because of the strength, flexibility, and fineness of the fibers. The outstanding features of asbestos are its ability to maintain its flexibility and to withstand temperatures as high as 385 deg C (725 deg F). At approximately this temperature the water of hydration is drawn off, and the asbestos becomes brittle and can be easily pulverized. The water content of asbestos, which is about 14 percent, accounts for the superior flexibility of this material over other types.

In selecting a grade of asbestos for electrical purposes, two factors must be considered: the amount of magnetic iron in the asbestos and the surface impurities which have not been removed. A grade of asbestos must be chosen which has a low content of iron, preferably less than 0.5 percent, which is so generally dispersed throughout the cloth that the possibility of large particles causing grounds is remote. Newer manufacturing methods have been found which remove impurities and conducting particles to a degree not considered economically feasible in the past. Also, the fibers can be prepared to much smaller dimensions. Untreated asbestos would, due to impurities and its moisture absorption qualities, have low insulating properties. When bent or stretched, asbestos exhibits uneven thinning in spots. Its fibers are smooth and shiny, making it easier for them to slide on one another and thus reducing the tensile strength.

Another disadvantage of asbestos for electrical insulation is that amounts up to 20 percent cotton are usually mixed with it to facilitate textile operations. If the apparatus is subjected to high temperatures, the cotton will burn or rot out, resulting in voids which decrease the thermo-conductivity of the windings and possibly leave room for conductor vibration.

Asbestos, like other cloths, is inherently lacking in electrical properties; therefore it must be considered solely as a physical spacing medium. Impregnation will impart to it the necessary electrical properties as well as the moisture-resistant qualities. Failure or loss of dielectric strength under high heat conditions or moisture are primarily failures of the impregnating materials used in the insulation system.

Asbestos in the form of cloth or paper can be used as a wrapper or tape, either alone or backed with paper, cotton, mica, and glass. Asbestos is also used in such applications as require a bulky resilient material. Because of its bulk it can act as a cushion for the end turns of machines where vibration is excessive.

By the use of a mineral filler and binder with asbestos, a thin non-inflammable, 100-percent inorganic paper-like material is obtained.* With the new processing methods of asbestos, means were found for combining the purified fiber with the mineral binder and filler to produce a continuous sheet of this combination, which has a strong resemblance to paper. It has the property of retaining its original tensile strength for a greater period of time at high temperatures. Its dielectric strength increases with an increase of temperature up to 500 vpm at 300 deg C (572 deg F) and then drops off. At 800 deg C (1472 deg F) it has a dielectric strength at 100 vpm.

The new combination has a better thermal characteristic than the standard asbestos paper, and a higher dielectric strength, but the same physical strength. It is used for magnet wire and layer insulation, as a mica backing material, and as a mica substitute.

Mica.—Mica has many of the desirable characteristics of the perfect electrical insulator, for it has high dielectric strength, low dielectric losses, high surface and volume resistivity, and high shearing and tensile strength. It is fireproof and non-inflammable, and at temperatures greater than its maximum safe temperature it simply calcines. Oils have a negligible effect on it.

For the purposes of this Circular it is convenient to classify raw mica into two groups—white mica and amber mica. White mica is

* T. R. Wallers, " 'Terratix' — A Thin Flexible Inorganic Insulation," *AIEE Technical Paper* 48-20, December, 1947.

the harder and has a maximum safe temperature of approximately 500 deg C (932 deg F). Amber mica is used mainly for commutator segment insulation, and because it will withstand 800 deg C (1472 deg F) it is widely used in heating appliances.

Mica is produced in several forms for use in electrical apparatus: commutator segment plate, hot molding plate, cold flexible plate, and composite insulation. Commutator segment plate is a general form containing mica and a minimum percentage of a polymerizing binder. After compression under heat, the binder imparts rigidity to the finished plate and prevents slippage of the mica films when subjected to heat and pressure. The usual thickness of the plate is from 0.020 to 0.040 in. It may be cut, sawed, drilled, and punched.

Hot molding plate for shells, tubes, V-rings, slot cells, and other forms contains about 15 percent binder. The binder is undercured so that it will soften at about 135 deg C (275 deg F) to permit molding and curing operations. After shaping, the curing process is completed, so that the finished product will have sufficient strength to resist mechanical loads at high temperatures.

Cold flexible sheet mica can be readily formed at room temperatures for applications such as slot insulation, commutator cores, etc. Because it is bound with nondrying oils, plasticizers, and resins, cold flexible sheet mica should not be subjected to high mechanical stresses.

For composite insulation the mica is backed with a carrier such as paper, silk, cotton, glass, or asbestos. The choice of the carrier is dependent on the required degree of temperature resistance, mechanical strength, flexibility, and the like. The percentage by weight of the mica in the composite is generally from 50 to 65 percent, the rest being binder and carrier. Frequently, several layers of mica and carrier are used for a single sheet. Binders have been developed which are not affected by oils. Mica products employing these binders are sometimes referred to as "Super." The mica in composite insulation greatly increases the surface leakage paths, and also reduces the effect of moisture because the moisture is absorbed by the laminations of the mica splittings.

In testing the composite insulation it is not possible to use standard devices such as an Elmendorf tear tester, because they are designed for varnished cloths. Only two devices are available for testing mica insulation—a thickness gage and a dielectric strength tester. Often a large manufacturer will require the meeting of a specification covering over-all thickness with a plus or minus tolerance, dielectric strength, grade of mica to be used and, if a backing material is to be used, the type of material and thickness. If the combination is to be utilized as a tape, it is understood by the manufacturer, usually from past experience or by word of mouth, whether the customer likes an oily, greasy tape or a dry, hard one. Therefore, handability is judged by each customer's shop personnel rather than by the use of testing devices. Frequently the reaction of the personnel in the shop is considered just as important as to satisfy the engineering department and the purchasing agent.

The quality of mica used and whether the combination is hand-laid mica or machine-laid are the determining factors of the dielectric strength of the composite mica material. As a general rule, all thin materials less than 7 or 8 mils have to be hand-laid. Greater thicknesses are usually machine-laid unless the user, regardless of the increased cost, specifies hand-laying. Since a detailed economic analysis is not feasible, the question of cost of the product will not be considered. In most cases hand-laying is done with large films of book mica, resulting in a 700-vpm material, whereas machine-laying with small loose mica results in a 500-vpm material.

Although many new insulating materials have been developed in recent years, none is about to replace mica in applications which require a high degree of electrical strength and moisture resistance under adverse conditions of temperature and corrosive atmospheres.

Plastics.—Among the newest developments in electrical insulation are plastics. John Sasso gives an interesting introduction:

> New types of plastics have been introduced with such frequency in the past few years that the impression may well have been gained that the chemistry of their structure is a hopelessly confused and complicated problem. The multitude of trade names adds to this confusion, although in some cases materials of almost identical structure may be known by from two to six or more trade names. It might seem at first glance that there is no logical definition of what is and what is not a plastic. This, however, is not precisely the case. The chemistry of plastics has been greatly clarified, and many workers are now studying their structure and the methods of manufacture.*

Few materials in the electrical field equal plastics in mechanical strength and dielectric properties. A great advantage over all other types of insulating materials is their adaptability to intricate molding and fabricating processes.

No single plastic can be considered as outstanding in all electrical properties. Analysis will indicate the different properties that will be required to insulate the apparatus under consideration; then a type which will fulfill these requirements may be selected.

* By permission from "Plastics Handbook for Product Engineers," John Sasso, ed. McGraw-Hill Book Co., Inc., New York, 1946.

Plastic materials fall into two basic groups: thermosetting and thermoplastic.

Under the thermoset group—materials that go through a chemical change when heated and become infusible upon cure—are the following: 1) phenol formaldehyde, 2) melamine formaldehyde, 3) furfural formaldehyde, 4) polyestics, 5) allyl alcohols. Certain ones of this group will withstand temperatures up to 202 deg C (400 deg F) before charring.

Those materials that will soften under heat and remain soft under heat, but upon cooling will harden, are thermoplastics. They include 1) cellulose derivatives (mentioned in Section 5 under Cellulose), 2) polystyrene, 3) vinyl copolymers, 4) methyl methacyiate, 5) vinylidene chloride.

The temperature limit for this group is 83 deg C (180 deg F), above which they begin to soften. If the temperature limit is exceeded for too long and if the temperature is such that the plastic can flow, permanent harm will have been done to the insulation.

In both groups, if the temperature limits are exceeded a large reduction in insulating strength, a higher leakage current, and a greater power loss will occur in the materials, besides mechanical deterioration.

A prime consideration in applying a synthetic to a piece of equipment is the products of thermal deterioration—a function of the chemical and physical nature of the material. Some synthetics have products of decomposition which are toxic, inflammable, or both. Such undesirable properties prevent the use of those synthetics. The gases can harm the nearby surroundings and human beings.

A second consideration is the effects of synthetic materials or their products of thermal decomposition on the adjacent parts in the equipment. Improper application may lead to corrosion and, in the end, failure of the apparatus. Because of a combination of corrosion and humidity, some types may form ionic solutions.

Another consideration is the effect of the synthetic materials on subsequent processes and treatments.

Since thermoplastics will soften under heat and flow away from critical areas, they cannot be used with varnishes that have to be baked. Certain ones cannot be used because in the presence of the varnish solvent they will be dissolved. Where a thermoset plastic has to be baked at high temperatures—e.g., silicones—thermal deterioration of the other material used in conjunction with it might occur.

The insulating properties of plastics are evaluated chiefly by dielectric strength, dielectric constant, power factor, dielectric loss, arc resistance, and insulation resistance. A knowledge of these allows determination of which plastic is most suitable for a given electrical application. The Appendix contains charts giving specific data on the most commonly used plastics.

Most plastics withstand high voltage peaks. The dielectric strength varies from 50 vpm for phenolic materials to 3000 vpm for foils of ethyl cellulose. Thin insulating foils increase in their dielectric strength as they become thinner, the peak occuring between 1 and 2 mils thickness. Temperature has little effect on the dielectric strength. Pronounced flow and weld marks may act as thin air gaps which have low dielectric strength. These may be detected by tests, so that the defective part may be discarded.

The dielectric constant varies from a low value of 2 for polystyrene to a high of 8 for mineral-filled phenolics. Dielectric constant times power factor determines values for dielectric loss.

The power factor can be said to be an expression of losses resulting from conductance and polarization in the dielectric materials. For low values of frequency, the loss due to conductance is small and that due to polarization is high. As the frequency is raised, conductive losses increase and polarization losses decrease. With increase of temperature, dielectric loss tends to rise.

Arc resistance is adversely affected by factors that contribute to surface conductivity. High temperature, short creepage paths, films of moisture and dust, and the pointed electrical contacts cause an early breakdown.

Insulation resistance is composed of two parts: volumetric, determined by the current leaking through the volume; and the surface insulation, determined by the leakage along surface. The former is affected by the reinforcing medium; the latter is governed mostly by the designer and is subject to many variables. Films of dust or moisture can account for previously unexplainable voltage drops. With an increase of moisture absorption and temperature the insulation resistance decreases.

Many plastics have low heat conductivity and low heat capacity; others have relatively high thermal conductivity. The thermal expansion is from 2 to 8 times greater than that of brass. This range presents a problem of unequal expansion when the plastic is used in conjunction with other parts. With an increase of temperature it may distort, crack, or buckle. Maximum safe continuous operating temperature is that at which the material will not become blistered or distorted or suffer a loss in appearance or mechanical strength.

Plastics are light, flexible, and resilient. Synthetic resins are subject to deterioration upon prolonged exposure to outdoor weathering, due to the sun's radiation and to cyclical wetting and drying.

In presenting the material on plastics, the authors fully realize that a complete treatment could not be given in the space available. The aim of this section has been to present some of the basic ideas on the major subdivisions of plastics as applied to electrical insulation. The fundamental data on the most popular plastics used for electrical insulation are reserved for the Appendixes.

Varnishes. —An insulating varnish is a solution of gums or resins (natural or synthetic) in a vehicle composed of oils and/or volatile solvents. Insulating varnishes are used to impregnate fibrous insulation, to treat insulating cloth or paper, and to provide a surface finish.

The primary function of a varnish is to compensate for the deficiencies of the other components of the insulation system. The varnish offers both mechanical and chemical protection, as well as an increase in dielectric strength and thermal conductivity. The mechanical qualities imparted by the varnish reduce the effect of mechanical vibration, magnetic vibration, and forces due to the rotation and/or changes in speed of rotating machinery. The varnish should provide protection against corrosive gases, moisture, acids, bases, oil, dust, and metallic particles. The varnish impregnation of a carrier (cotton, asbestos, etc.) will appreciably increase the thermal conductivity of the composite insulation. Since most of the commonly used carriers have in themselves a dielectric strength equal only to that of an equivalent thickness of air, the dielectric strength must generally be supplemented by varnish impregnation.

The characteristics to be considered in the selection of an insulating varnish have been listed by B. F. McNamara as follows:* 1) penetration, 2) depth of drying, 3) binding and adhesive properties, 4) high softening temperature, 5) chemical stability of permanence, 6) insulation resistance, 7) waterproofness, 8) oilproofness, 9) alkali resistance, 10) acid resistance, 11) heat endurance, 12) physical toughness, and 13) flexibility. The initial electrical characteristics of the varnish, such as insulation resistance and dielectric strength, are generally satisfactory for most of the applications within the scope of this paper. The limiting factors are the effects of the foregoing characteristics on the electrical properties of the composite insulation.

Impregnating varnishes may be either air-drying or baking. The impregnating-baking type is further subdivided into two groups:

* "Functions of Electrical Insulating Materials and Electrical Insulating Varnish," B. F. McNamara. Addresses to Iron and Steel Engineers, Birmingham, Ala., Oct. 27, 1947.

the conventional and the thermosetting. The hardening of the conventional-type varnishes is a gradual oxidation and polymerization process. The thermosetting varnish is a heat-reactive synthetic varnish which cures by polymerization and not by oxidation. After impregnation the apparatus is heated to a specified temperature for a certain period of time. The thermosetting varnish then "sets" permanently through the piece of equipment, even in deep-seated parts. The result is an infusible, strongly bonded insulation. When a conventional type is used, only the outer parts are cured initially, since the oxidation process proceeds inward gradually. For conventional varnishes a high oil content gives slow drying but long life; a quick-drying varnish is less tough and has a shorter life.

Generally speaking, the black varnishes have better resistance to moisture than the clear varnishes. The clear varnishes are recommended for use in oil-cooled transformers because of their superior performance in the presence of oil. Although the synthetic phenolic base insulating varnishes have exceptionally high heat resistance, they will not have sufficient resistance to the transmission of steam or moisture vapor if the varnish film is not thick enough. Recently improved varnishes of the phenolic-alkyd heat-hardening type have been developed for the purpose of providing better protection against dirt, oil, grease, and other foreign matter. The varnish has good penetration characteristics and its surface is smooth and resistant to oil, acid, and alkali. Such varnishes must strike a balance between a hardening that is resistant to foreign matter, and coil inflexibility.

Because about 50 percent of a varnish consists of the solvent which is removed in the curing process, "solventless" varnishes have been developed which eliminate troublesome voids, although in deep coils some difficulty has been experienced in securing thorough impregnation and hardening. The "solventless" varnish is a mixture of the gums or resins and the oils.

Care must be taken not only in the selection of a varnish but also in its preparation and use. The viscosity is determined by the amount and type of solvent added to the varnish. The sequence of operations generally followed after the varnish has been prepared is: pre-heating, dipping, draining, and baking. For good results care must be taken in each of these steps. The selection of a varnish is a matter of balance; no one varnish will have all the qualities the user might desire. The selection should take into account the physical facilities which the manufacturer has available, for some varnishes may have a baking cycle or a baking temperature that would rule out their use.

The enamel used for magnet wire is a special form of insulating varnish. In addition to the usual requirements it must adhere to the metallic surface.

An attempt was made to classify all existing varnishes for comparative purposes into general groupings. This attempt was not accomplished; it is difficult to assemble in one chart information from various manufacturers. Thus far no standards for direct comparison are available. Each manufacturer gives pertinent information on his own varnishes, and in selecting a varnish for a particular use consultation with the manufacturer is advisable.

To show the difficulty of coordinating and the need for specific standards of classification, two charts from well-known manufacturers are reprinted at the end of the body of this circular. The charts reveal that information is available, but not on the same comparative basis.

This account of varnishes ends with a mention of polysiloxane, or silicones as they are commonly called. They are treated individually here because they have resulted in the establishment of the Class H range of electrical insulation.

Silicones are a new class of semi-inorganic polymers made of sand, brine, coat, and oil. The greater thermal stability of the silicones than of organic materials is due to the fact that the silicone-to-oxygen bond in the silicone chain is stronger than the carbon-to-carbon bond in organic materials. The surface of the organo-silicon compounds is similar to the surface of a hydrocarbon compound, a fact which accounts for the excellent moisture resistance of the silicones.

Silicone resins are produced in two types: 1) the insulating-varnish type, used to coat inorganic materials such as glass, asbestos, and mica, and also as a binder in mica-glass sheet; 2) the thermosetting-resin type, used for laminates and similar purposes requiring a hard rigid material.

In general, the electrical and mechanical properties of silicones are equal or inferior to those of the conventional organic materials. It is the chemical properties that particularly recommend them. They are resistant to high temperatures, oxidation, moisture, and chemical agents. The initial mechanical and electrical properties of a silicone may in some cases be inferior to the corresponding properties of an organic varnish. However, if the application is such as to emphasize thermal stability, moisture resistance, and chemical resistance, then after a period of operation a silicone-insulated piece of equipment should have mechanical and electrical properties superior to those of a similar machine insulated with organic varnish.

Under normal operating conditions there is little advantage in the use of silicones instead of the organic varnishes. It may, in fact, be disadvantageous. However, under abnormal conditions of temperature, moisture, and corrosion the advantage of this unique material becomes apparent. The use of silicones permits greater life under conditions of high ambient temperature, high humidity, and corrosive agents; larger overloads with less danger to the equipment; and greater output for a given weight of apparatus.

Silicones have an established place in the electrical insulating industry. In some instances they have replaced organic varnishes that were not suited to the job. They should, in general, not be thought of as a replacement but as a new material opening a new field of high-temperature insulation, and should be so applied.

Although many hundreds of varnishes are available, a comparison of the properties of a few typical kinds suffices to give a general view. Special problems justify individual treatment, but in general it is unnecessary and inadvisable to keep in stock a large number of varnishes; the needs of most applications can be met by a few standard types.

6. *Liquid Dielectrics*

Oil is the most important liquid dielectric for transformers.

It has two main functions—as a cooling medium and as an insulating medium (electric strength being greater than air). A gum-like material solid at room temperature could serve as the insulating medium except that oil has the advantage of being self-healing. Any momentary failure of the oil due to a temporary overvoltage is cleared by the liquid, which flows to the break to reinsulate the path. For a given transformer operating at a fixed load, the operating temperature depends on the "cooling" characteristics of the liquid dielectric. The better these characteristics, the lower will be the operating temperature.

Any liquid which is miscible with or has any affinity for moisture must be ruled out as an insulating medium, because of the chemical reactions that will occur in the presence of moisture. Oil was chosen chiefly because of its good qualities against moisture, even though its inflammability is a disadvantage.

The specifications which a transformer oil must meet are six:

1. It must have high dielectric strength.

2. It must be as free as possible from sludging, by having a high degree of stability at operating temperatures.

3. Oil with low viscosity and high heat conductivity is desired for maximum heat transfer.

4. It should be one that has been refined with no presence of acids. Over-refined oil should not be used, because of its tendency to form organic acids.

5. The oil must have a specific gravity which is decidedly different from that of water. When the water comes in contact with the oil, it will immediately settle to the bottom.

6. It should have a high resistance to emulsion.

Mineral oils that do not satisfy these specifications will deteriorate, mainly because of water and oxidation. During aging in service, oxidation products will be formed which will collect on the tank walls or on the windings in the form of solids. Such a collection, commonly called sludge, will interfere with the cooling process and may thereby produce a complete destruction of the transformer. The amount formed in a given oil depends on the temperature and the time of exposure of the oil to the air. The effect can be minimized by careful refining and selection of the oil, which determine the kind of oxidation and the products which are formed. There are means of regenerating oil having a considerable amount of sludge.

Breakdown of oils can occur by either of two well-known methods, the pure electric and the thermal. The former is independent of the influence of temperature and pressure, and occurs mostly because of impulse voltages. The latter is more common for oils: it results from sustained application of a voltage, the condition under which transformers are used in practice.

Tests have yielded the following facts about two groups of oils.

Group A*

(1) Oils with different physical characteristics show wide differences in the electrical characteristics under the limited-oxidation tests. For example, certain oils will give maximum electrical instability, as indicated by high power factor, with the oil contacting copper in the absence of oxygen. Generally these oils will produce lower power factors with increasing amounts of available oxygen. Other oils give a maximum electrical instability as indicated by high power factor, with amounts of available oxygen in the range of a few hundred cubic centimeters of oxygen per kilogram of oil.

(2) Over-refined oils generally give good electrical stability in the initial period of a continuous-oxidation test. Such oils generally produce large amounts of water and low-molecular-weight acids.

(3) Representative straight hydrocarbons exhibit somewhat the same characteristics under limited-oxidation tests as apply to commercial electrical insulating oils. Accordingly, it is believed that the type of hydrocarbon plays at least some part in the characteristics of a given mineral oil.

(4) The non-hydrocarbon components of a mineral oil determine to a large extent the characteristics of that oil under limited-oxidation. In many cases, the addition of a few tenths of a percent of added compounds may change very greatly the characteristics of an oil.

(5) It has been observed that mineral oils may change their limited-oxidation characteristics with time of standing in a container.

* Balsbaugh, J. C., and A. G. Assaf, "Electrical Stability of Electrical Insulating Oils Under Limited Oxidation," *AIEE Transactions*, Vol. 62, 1943.

Group B*

(1) In the continuous-oxidation tests the inhibitors which reduced oxygen consumption, in general, reduced the electrical losses.

(2) Varying concentrations of inhibitor and available oxygen and copper surface produced diverse electrical losses.

(3) Sulphur additives. Sulphur compounds in concentrations found in refined oils may increase or decrease the electrical losses produced by a limited oxidation, depending on their type and structure.

Group C†

(1) The dielectric properties of insulating oils are considerably affected by the stressing in service.

(2) Oils which already display inadmissibly high dielectric losses due to aging can be restored to their original values by means of treatment with Fuller's earth.

(3) The dielectric losses of new oils cannot serve as a basis for design, because they greatly increase in service due to alteration. It is therefore absolutely necessary to subject the oils to an aging process and to remeasure the losses in this state.

Since oil is inflammable, chlorine derivatives of aromatics were developed which were fireproof and had the required stability. These liquids are known as aroclars or by various trade names.

The aroclars are non-inflammable, very resistant to oxidation, nonconductive to sludge formation, and nonconductive to the development of acidity like the mineral oils. They are also good coolants for transformers. When decomposed by heating or arcing they develop hydrochloric acids, which are solvents for most insulating varnishes and materials. As for leakage, surface discharge, and breakdown voltage, the aroclars behave in a manner similar to mineral oils of medium quality. The greatest difference lies in the magnitude of their dielectric losses; the aroclars are subject to a greater deterioration due to aging than the minerals oils. They can be regenerated in a manner similar to that used for the oils.

7. *Comparison of the Properties of Various Insulations Under Unusual Conditions of Moisture and Temperature*

The insulating materials have been discussed individually; this section compares a few properties of some of these materials. The purpose is to give examples of comparisons that have been made and to indicate the necessity of a comparison in the selection of the components of an insulating system.

To compare the moisture characteristics of glass fiber, cotton, and asbestos, a series of tests was made by K. N. Mathes and H. J. Stewart. Curves were drawn from the data showing the percent

* Assaf, A. G., and J. C. Balsbaugh, "Mineral Insulating Oils, Effect of Additives on Electrical and Chemical Stability," *Industrial and Engineering Chemistry*, Vol. 35, No. 8, August, 1943.

† Putz, A., and J. Biert, "The Dielectric Losses of Oils and Other Insulating Oils," *Brown Boveri Review*, Sept.-Oct., 1943.

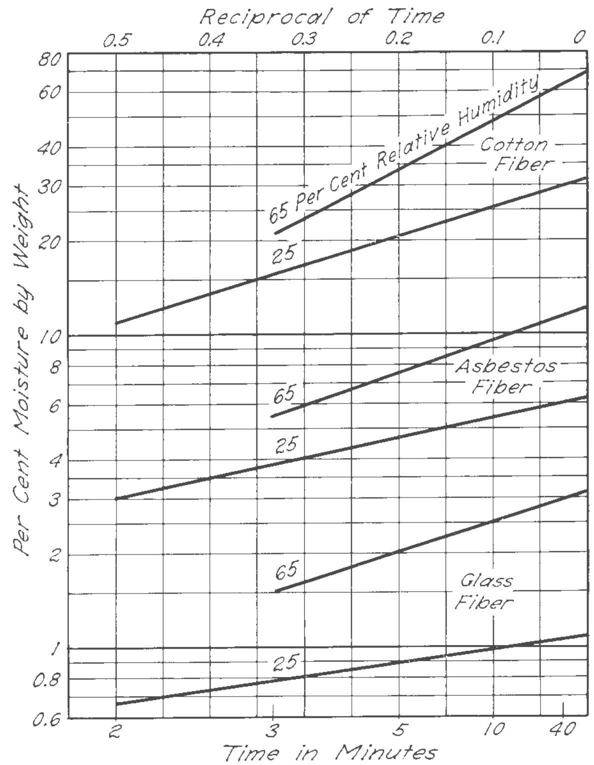

FIG. 1. INCREASE IN PERCENT MOISTURE *vs.* MINUTES AT 25 PERCENT AND 65 PERCENT RH, AT 25 DEG C

regain of moisture as a function of time at 65 and 25 percent relative humidity, and the decrease in percent moisture versus time. It can readily be seen in Figs. 1 and 2* that glass fiber has better moisture characteristics than either cotton or asbestos under the specified test conditions. Other tests also indicate the moisture-resistant qualities of glass fiber; however, under conditions of high humidity it has been found to be comparable to cotton only when percentage change in dielectric strength is taken as the criterion.

Insulation resistance is one of the accepted criteria of the effect of moisture on insulation. To emphasize the difference between asbestos and glass materials, and also the difference in sizing materials, the curves of Fig. 3* were drawn. Resistance is plotted as a function of time at 100 percent relative humidity and 40 deg C (104 deg F). The coils used for the measurements were wound to duplicate field

* Mathes, K. N., and H. J. Stewart, "Asbestos and Glass Fiber Magnet Wire Insulation," *AIEE Transactions*, Vol. 58, June, 1939, p. 251.

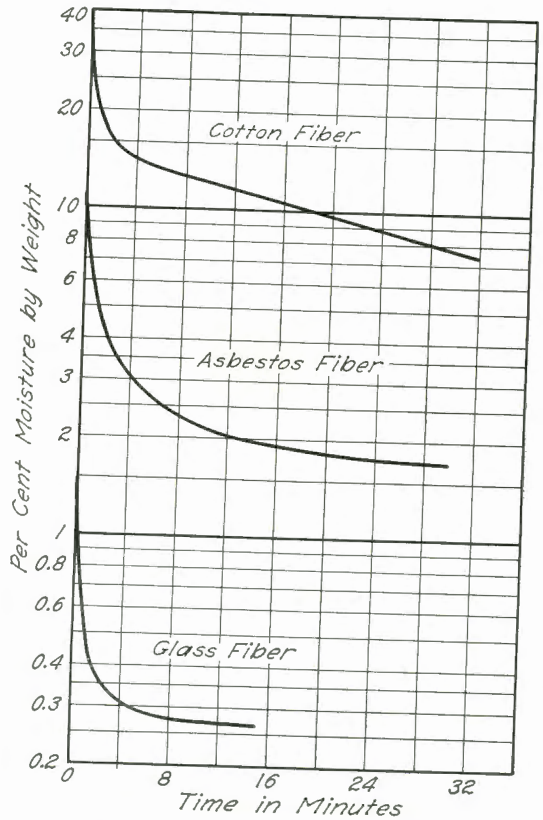

FIG. 2. DECREASE IN PERCENT MOISTURE *vs.* MINUTES AT 50 PERCENT RH AND 25 DEG C

coils and were completely varnish-treated. In the upper curve the original sizing material was removed from the fibers and replaced with an improved material before varnish treatment.

As has been pointed out, the ability of an insulation to withstand winding operations is as important as its other characteristics. Not only resistance to abrasion but elongation and impact strength may be of primary importance. The relative characteristics of cotton, asbestos, and glass fiber when subjected to impact such as might take place when the coil is forced into slots or into a form, are shown in Fig. 4*, which gives a comparison of the dielectric strength of these materials when subjected to increasing direct impacts.

* Mathes, K. N., and H. J. Stewart, "Asbestos and Glass Fiber Magnet Wire Insulation," *AIEE Transactions*, Vol. 58, June, 1939, p. 291.

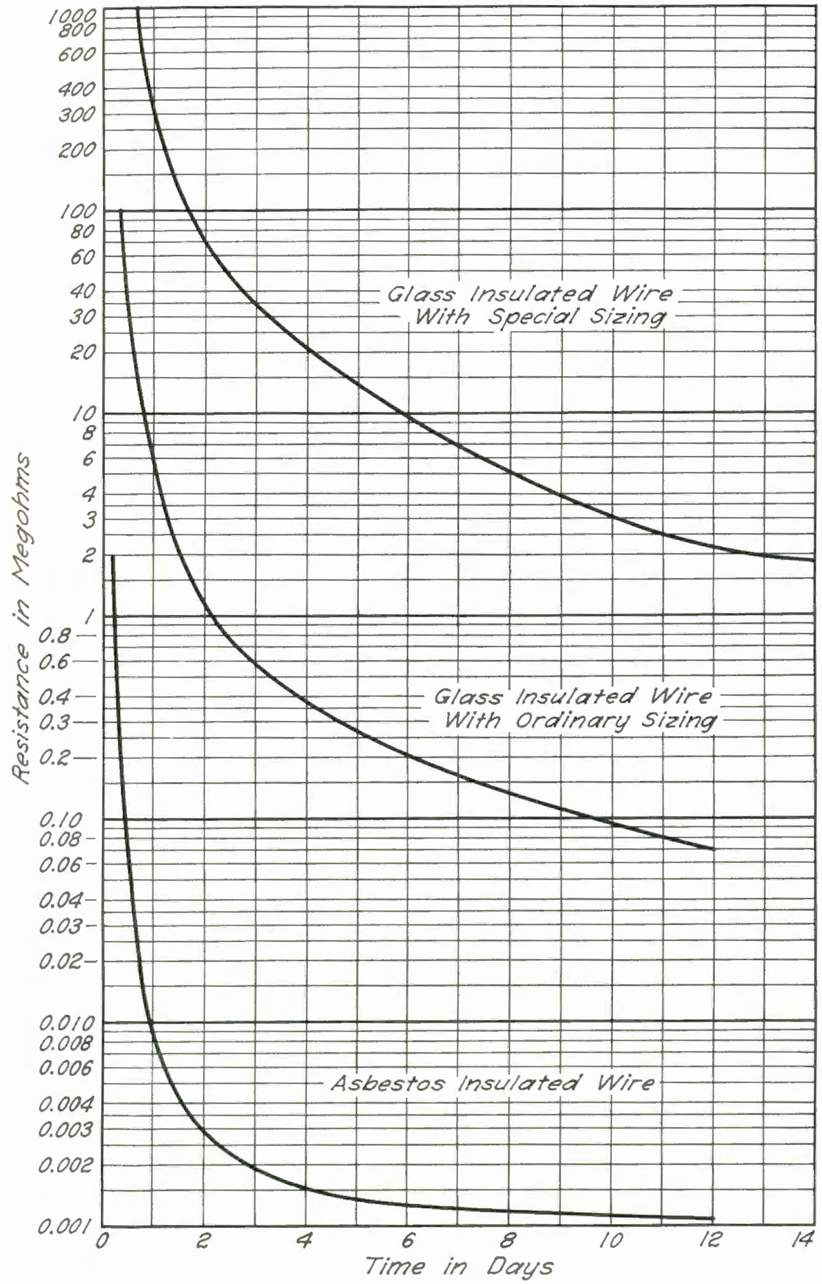

FIG. 3. ELECTRICAL RESISTANCE *vs.* DAYS AT 100 PERCENT RH AND 40 DEG C

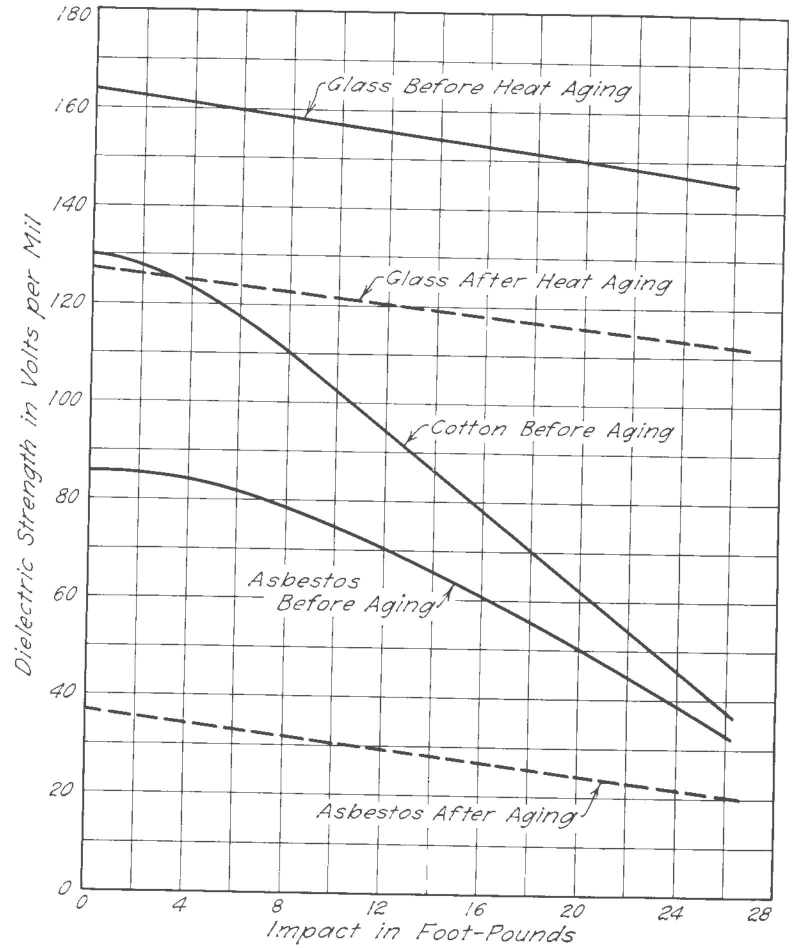

FIG. 4. DIELECTRIC STRENGTH *vs.* INCREASING IMPACT

The effect of heat on the tensile strength of asbestos, cotton, and glass fiber tapes is shown in Fig. 5.* The curves show that glass tape is 2 20 times stronger at room temperatures than similar tapes made of other commonly used fibrous materials. The strength of glass tape does not diminish appreciably up to 315 deg C (599 deg F), and after 24 hr at 425 deg C (797 deg F) it still retains half its original strength.

* Atkinson, F. W., "Fiber Glass—An Inorganic Insulation," *AIEE Transactions*, Vol. 58, June, 1939, p. 278.

With the advances made in the manufacture of insulating varnishes in the last few years it has become increasingly apparent that the limiting factor in the operation of organic insulation at high temperatures is not the varnish or treating compound but the carrier on which it is applied. Cotton, when impregnated or coated and subjected to high temperatures (about 125 deg C, or 257 deg F)

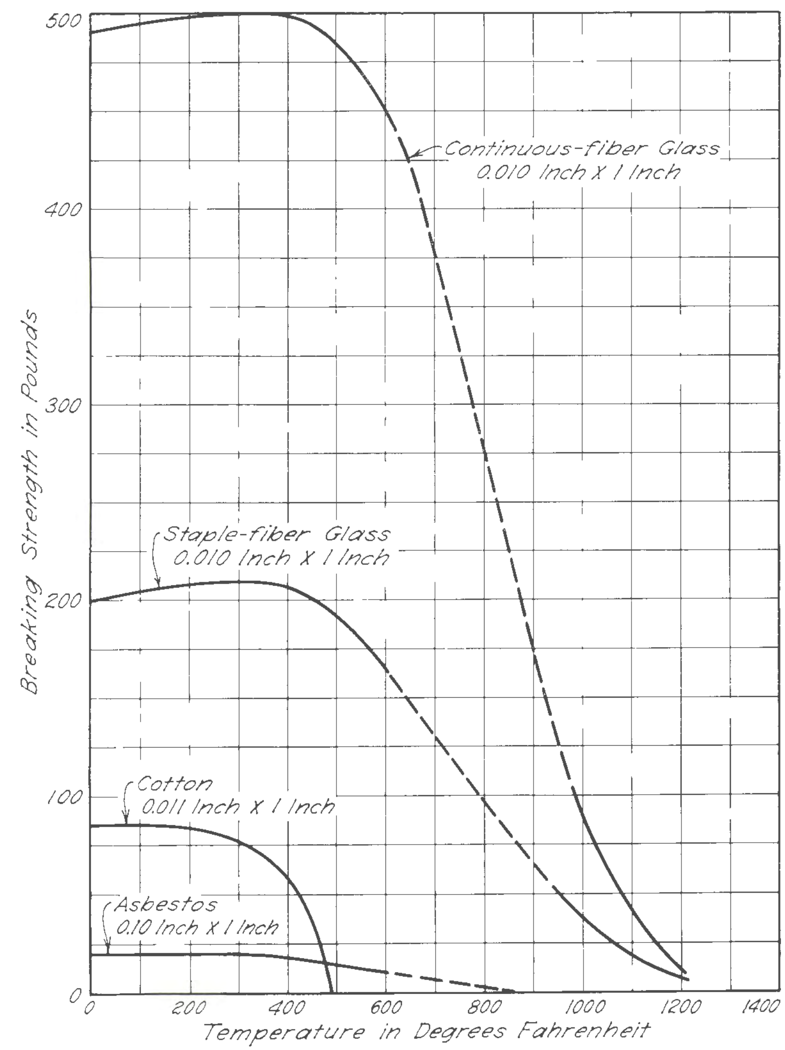

FIG. 5. EFFECT OF HEAT ON TENSILE STRENGTH OF ELECTRIC TAPES

fails only in a mechanical sense—that is, fails insofar as tensile and tearing strength are concerned—but does not fail electrically; the dielectric strength of the varnish or compound will, if anything, be higher after the heat treatment. When glass is used as the carrier, good electrical and mechanical properties will be assured even after exposure to high temperatures for long periods of time.

When a glass fabric is used, it serves merely as a matrix to carry the insulating varnish. The extent of the varnish deterioration over long periods of time is extremely important. The most characteristic effect of the varnish deterioration is the slow embrittlement and tendency toward cracking, which may seriously impair the dielectric strength. In contrast, if mica is compared to glass as an insulator it can be seen that the overlapping flakes of pasted mica depend on the varnish film only as a binder.

The limiting factor with impregnated glass is the impregnant, whereas with Class A insulation it is the fabric. Tests of numerous varnishes on glass and cotton fabrics definitely show that the better heat-resistant varnishes will stand temperatures considerably in excess of those which cause cotton to lose practically all its mechanical strength. Three different samples of yellow varnished cotton cambric were held at 125 deg C (257 deg F) for 168 hr and then were bent around a 1/8-in.-diam mandrel 180 deg. Only one did not crack. The same test was performed on yellow varnished glass cloth; of six samples, each varnished by a different company, all passed the test. Several of the better commercial varnishes were tested in this way when applied to glass cloth; the combination passed this test after a week at 175 deg C (347 deg F). It seems reasonable to assume that the temperature limits of Class A insulation are determined by the fabric and not by the impregnant.

IV. Insulation Problems and Design Considerations in Electrical Machinery and Transformers

8. *Introduction*

With the background presented in Chapters II and III, it is now possible to enter into a practical discussion of the principles behind, and the problems encountered in, the application of insulation. The treatment is organized as follows:

A. Desirable Characteristics of Electrical Equipment
   Those characteristics and factors which are important to the user in the selection of electrical equipment.

B. Rotating Machinery
   1. General design considerations for machines.
   2. Materials used in specific portions of machines and special considerations involved.

C. Nonrotating Machinery
   1. General design considerations for transformers.
   2. Materials used in specific portions of transformers and special considerations involved.

Sections B-2 and C-2 are treated in part verbally and in part by charts indicating and comparing general groups of materials that are used for a particular application. For a given set of characteristics it should be possible to choose from these charts a general type of material for the application being considered, and then to go to the Detailed Chart at the end of the circular and choose from within the group a single material that will closely satisfy the desired characteristics.

The tables at the end of the chapter present in concise form an over-all picture of the insulating materials as they pertain to motors, generators, and transformers.

9. *Desirable Characteristics from User's Viewpoint*

In the choice of electrical equipment it is obvious that the apparatus must be of such size and design as to be capable of taking the load placed on it. Thereafter the choice of a piece of equipment is made on the basis of economy—not of the least initial cost but of over-all economy considering the following factors, each of which must be weighted in with the initial cost: 1) reliability, 2) life, 3) voltage rating, 4) maintenance, 5) size and weight, 6) efficiency and power factor, 7) appearance and safety.*

* The desirability of using equipment having a voltage rating that will not necessitate the installation of auxiliary power supply equipment is apparent and also external to the purpose of this section; it will therefore not be discussed.

In many cases the unexpected failure of electrical equipment will mean heavy financial loss to users, because of stoppage of production or of damage to material being processed. Some applications demand the greatest reliability of operation possible—for example, traction motors on electrified railways. Most failures can be attributed directly or indirectly to the insulation system. The choice of materials or the workmanship may be at fault, though the blame for failure of the insulation must sometimes be placed on incorrect application by the user. For instance, to use a standard Class A motor under conditions of very high humidity and intermittent service is to invite trouble. Consultation with the manufacturer will often prevent costly mistakes in application.

Long life is not always a requisite for electrical equipment. New methods, and obsolescence or wear of associated equipment, may necessitate replacement after a few years. It is therefore customary to decide before purchase the number of years the apparatus is to be used. For example, the life of an entire washing machine may be 20 yr, but the motor itself will probably not be used more than the equivalent of 1 yr of continuous operation. It is clearly absurd to use a motor insulated with materials capable of withstanding continuous operation for 10 or 20 yr. Similarly, standard open-frame Class A apparatus should not be used where temperature, moisture, or chemical conditions are abnormal; the life under these conditions would justify the use of some other type of equipment, perhaps totally enclosed Class A, Class B, or Class H apparatus. If the ambient temperature is very high, a larger Class A unit might be used at part load so that the temperature rise would be less. This choice would increase the life; but first the possibility of using Class B or H apparatus should be investigated.

Several rules have been formulated for the determination of the life of insulation. One is the "10 deg C rule," which states that for each 10 deg C rise of operating temperature the life of a machine is reduced by half. This rule will apply to many insulating materials, but not all. Consider a machine having a life of 10 yr when operated at a hot-spot temperature of 100 deg C. If the unit is operated at 100 deg C the life would be reduced to 5 yr. If the machine were operated for 2½ yr at 110 deg C and for the rest of its life at 100 deg C the life would be 7½ yr. While these rules are not rigorous they indicate the effect of overloads on the insulation system and therefore on the life of the machine.

The amount of maintenance is worth consideration from the user's viewpoint. It will vary greatly with type of motor, temperature class, and operating conditions. A definite schedule of inspection should be set up, dependent in frequency upon these factors, but in all cases there should be a periodic check. Proper maintenance and inspection of the insulation will greatly increase the reliability of the equipment.

In some applications, such as aircraft or streetcars, minimum size and weight for a given rated load are inherent, or at least highly desirable, requirements because of the nature of the application. At other times minimum size and weight are important because of frequent starting and stopping. An example is furnished by the motors driving machine tools. Since those having large size and weight have a large amount of inertia, the kinetic energy stored within the rotating machine at any given speed will be correspondingly large. Frequent starting and stopping, therefore, requires large amounts of power, and results in considerable heating within the motor. The size and weight are decreased by using an insulation system having a higher over-all space factor, or by working the materials harder. The operating temperature will generally increase if the materials are worked harder; this necessitates a change in materials from Class A to Class B, or from Class B to Class H.

Efficiency and power factor differ from one design to another and determine the cost of power for the user in most power applications. However, they differ so little as to be minor considerations in most cases. Many of the tests on high temperature units indicate lower efficiencies than with conventional temperatures. Often the decrease in size and weight will more than overcome this factor in high-temperature apparatus.

The stress placed upon appearance is somewhat less tangible than the interest in safety. The factor of safety merges with that of reliability, and will be considered here in only one respect. While there are advantages to high-temperature operation, it should be remembered that a high frame temperature will coexist with a high hot-spot temperature. The possibility of injury to workmen is obvious, yet might be easily overlooked.

10. *Rotating Machinery*

Design Considerations. There are four main topics to be considered under this heading.

(a) Effect of Application on Design. The design of the insulation systems of rotating machinery is governed mainly by the proposed application of the equipment. To secure the maximum performance the apparatus should be "tailored" for each appli-

cation. If "tailored" is not justified in view of the size of the installation, a standard unit must be chosen to meet the requirements even though there is a resulting loss of performance.

The application governs the design of the insulation system through factors which directly affect the machine. These factors are:

A. External conditions—moisture, chemicals, dust, ambient temperature.

B. Load conditions—length and frequency of the operating period, degree and frequency of overloads, starting and stopping.

That moisture, chemicals, and dust affect the insulation system and influence the choice and use of the insulating materials is obvious; this has been brought out in previous sections. A detailed account of the effects of the ambient temperature is reserved for the discussion of operating temperatures, but it should be pointed out here that if the ambient temperature is high, the hot-spot temperature under normal load will be high and the life of the machine will be reduced.

Except for the high-temperature machines, the rating of a unit is dependent mainly on the permissible hot-spot temperature of the insulation. The rated load is that load which under continuous operation will produce the rated hot-spot temperature. If the load is intermittent and of brief duration it may be possible to exceed the rated load of the machine without exceeding the hot-spot temperature. Hence, for a given load a machine with a smaller rating could be used. If a load greater than rated load is placed upon a machine for only a short time it may be called an overload. However, if the duration of this heavy load is considerable it should be considered the normal load for the application, rather than an overload. Hot-spot temperature resulting from overloads may or may not exceed the rated temperature, depending on the temperature of the machine at the time the overload was initiated and on the duration of the overload. Temperatures greater than the rated hot-spot temperature are permissible, though the rate of aging of the insulation is accelerated and the life of the machine shortened. If the application involves frequent starting and stopping, the insulation will receive additional mechanical wear due to the large forces involved and the shifting of conductors in the slots.

In addition to the foregoing factors that directly affect the insulation of the machine, consideration must be given to other requirements which exert a somewhat less tangible effect on the design of the insulation system. Reliability, life, and low weight need to be considered in many applications. In most cases the requirements

are indefinite, and the degree to which these qualities will be satisfied for a particular machine will depend on the manufacturers' desires and upon the selling price of the machine. The user is often unwilling to accept the small increase in cost which would result from the use of better insulating materials and more careful workmanship, even though it would mean a more economical machine in the final analysis.

(b) Selection of Operating Temperatures Many articles have been written on the virtues and vices of high-temperature operation of machines, especially since the appearance of silicone insulation several years ago. Yet caution must be used in reading these papers; for, while the data as presented may be correct, they as well as the conclusions drawn therefrom may not be complete. The fact that a material or combination of materials will withstand very high temperatures for many years does not mean that it should be used as a wholesale replacement for other materials. The high-temperature materials have an important place in the electrical industry but must be used only where they are economically justified, after all factors are taken into account.

High-temperature machines have their greatest value where:

1. The ambient temperature is high
2. Small size and weight are especially desirable
3. The load requires frequent starting and stopping
4. Periodical overloads are encountered
5. Greater protection is desired against failure under unpredictable and abnormal conditions such as voltage fluctuations and insufficient ventilation.

To indicate the difference between the effects of high ambient temperature upon low-operating-temperature and high-temperature machines, consider two such machines rated for 60 deg C (108 deg F) and 100 deg C (212 deg F). Increase in ambient temperature will reduce the permissible rises to 30 deg C (86 deg F) and 70 deg C (158 deg F). For purposes of illustration it can be assumed without too great an error that the permissible load on a machine equals the product of the rated load times the ratio of the actual permissible temperature rise to the rated permissible temperature rise. If in the example chosen both machines had the same rating when operated at the same rated ambient temperature, then the increase of ambient temperature would cause the low-temperature machine to have now only $\frac{30}{60}$ of its original load rating and the high-temperature machine to have $\frac{70}{100}$. To conclude, the higher the rated operating temperature of a machine, the less will be the reduction in permissible load due to high ambient temperature.

Certain applications have as a major requirement low size and weight. By working the materials harder and decreasing the size and weight a machine of a given rating can be made smaller. Other applications require that machines having the same size, weight, and load rating as a standard Class A machine be operated in conditions of high humidity and corrosive chemicals. One solution is to use a totally enclosed nonventilated (TENV) machine. Because the size and weight are fixed and the machine is nonventilated, the operating temperature must be higher in order to dissipate the internal losses of the machine.

If a machine is started or stopped electrically it will take large currents, with resulting energy losses within the machine. If the starting and stopping is frequent the average losses will be high and the machine may have to dissipate much more heat than when operating continuously under rated load. If the size of the machine is reduced by using less copper and iron, the temperature rise will be greater but the WR^2 of the machine will be reduced. Hence less energy will be required to start or stop the machine, and the starting and stopping losses will be reduced.

The first consideration in high-temperature operation is thermal aging and the resulting mechanical and electrical deterioration of the insulation. Since this is discussed elsewhere it is only mentioned here.

The following are a few of the other factors which present difficulties in high-temperature operation:

1. Reduced overload capacity
2. Difficulties due to
   a. Bearings and lubrication
   b. Metallurgy
   c. Thermal expansion
   d. Iron loss
   e. Copper loss

The same percentage overload will reduce the life of a high-temperature machine more than it will reduce the life of a low-temperature machine. The proof of this, not given here, is based on the same assumptions as were used in the discussion of ambient temperatures and is generally similar.

When equipment is operated at high temperatures the effect of these temperatures on all parts of the motor is important. At 150 deg C (302 deg F) some types of bearings start to anneal; obviously, a bearing must be used which will stand the increased heat as well as the compressive stresses due to expansion of the shaft, or else one which is artificially cooled. Also, a lubricant must be used which can stand the higher temperature without decomposing, oxidizing, or losing its lubricating properties. To meet this need, silicone lubricants as well as special organic greases have been developed. They have had a considerable degree of success.

Other metallic parts of machines are also affected by high temperatures. For example, the soldering used with bonding wire is affected at about 300 deg C (572 deg F); pure copper becomes brittle at about 160 deg C (320 deg F). Differential thermal expansion creates stresses on various portions of the apparatus and results in abrasion of the insulation.

Changes in iron loss with increased operating temperature are small and have little effect on efficiency. However, an increase in operating temperature from 100 deg C (212 deg F) to 160 deg C (320 deg F) will reduce the efficiency more than 1 percent, which means that the losses are increased about 10 percent. If the losses were to remain constant, 18 percent more copper would be required.

The most prominent materials in the field of high-temperature insulation are mica, silicone, asbestos, and glass fiber. Various combinations of these have been and are being used successfully. Tests indicate that silicone-insulated machines will withstand Class H temperatures for several decades. A silicone-insulated motor was operated at 300 deg C (572 deg F) until failure. Then by a 12 deg C (54 deg F) life rule the life at 180 deg C (356 deg F) was estimated to be about 80 yr. Actual life tests at 180 deg C (356 deg F) are impracticable, because of the length of time necessary to secure failure. Estimates of the life at operating temperature must be extrapolated from accelerated tests by some such rule as the 12 deg C rule.

(c) Considerations of Speed The principal advantages of high-speed machines are reduced size and weight, and a consequent saving in materials. Since the design starts with the armature slot, and since the effective use of the tooth and slot largely determines the rest of the design, it is important to utilize the active materials to the best advantage at these places. In traction motors, even a few mils saving in the width of the slot may permit a considerable percentage more of copper in the slot or reduction in field

ampere turns, or even the use of a smaller diameter armature. The decreased size and weight allow a decrease in the size and weight of the chassis also.

More effective fans can be designed for high-speed armatures, so that the energy losses within the machine can be dissipated more rapidly and the operating temperatures kept within reasonable values in spite of the reduced size. Another factor to consider is that high-speed units are inherently more efficient than low-speed.

The higher speeds increase the centrifugal forces on the windings and therefore on the slot liners, coil insulation, slot wedges, etc., with a resulting increase in the wear on the insulation. This effect can readily be minimized by a careful choice of the insulating materials and a varnish which will not soften or "throw" at high speeds and temperatures.

(d) Special Considerations for Machines Throughout the report the principle of selection of the insulating material to fit the application has been stressed. This is proper, but in practice the user generally chooses one out of a number of standard machines. Hence, from his viewpoint the problem is to determine his needs and then choose a standard unit having those characteristics which will at least meet the minimum requirements. The manufacturer's problem, on the other hand, is to design and produce machines capable of operating successfully under varied conditions, and to specify exactly the operating conditions that each type is capable of withstanding.

Many of the design factors applying to synchronous machines apply equally well to induction motors and d-c motors, since they are generally similar. However, certain parts of the machines differ radically; for example, d-c machines have special commutating problems. Commutation difficulties are experienced in such applications as steel mills where the commutator quickly becomes dirty and rough, with resulting sparking and wear.

Of the many induction motors in use today only a few have an operating cycle or operating conditions that would necessitate other than a Class A motor. When special motors are required the motor must be redesigned. Class B motors would be used without a radical change of design, but with higher temperatures the expansion of the rotor will require larger air gaps. Since the distribution of losses is different for high-temperature operation, a change in the ratio of copper to iron should be considered. The insulation between laminations is usually given little consideration, but in the case of high temperatures it may break down and give trouble. The rating of a general-purpose induction motor is based mainly on the breakdown

torque and size of the shaft and bearings, the temperature rise generally being a secondary consideration.

Insulation Materials Used. —Having discussed the general design considerations for machines, the factors entering into the choice of a material for a particular part, and a comparison of these materials will now be presented. The charts accompanying this chapter contain numerical values (in roman type) wherever possible. Where numerical values were not obtained a relative value (in blackface type) of the property with respect to the other materials was assigned, based on a rating system of 1 – 10. A rating of 1 indicates that the material thus designated is most desirable for the property named.

The Application Charts contain the general grouping or combinations of insulating materials that may be used for a particular part of the machine. After selecting the type that will best satisfy the design factors to be met, reference may be made to the Detailed Chart, which presents a breakdown of the general groupings and thus permits a more detailed comparison of the insulating materials.

Two factors must be constantly remembered while using the charts. The first is that frequently the following rules of thumb are used as a guide by engineers: 1) raw mica has a dielectric strength of about 1500 vpm; 2) a varnish film has a dielectric strength of about 1500 vpm; and 3) untreated cloth has the dielectric strength of air — about 100 vpm. When computing the dielectric strength of a material where one component is low in dielectric strength and the other is very high, disregard the low dielectric strength, and divide the total dielectric strength of the high dielectric material by the over-all thickness. For example, a composite mica material made up of 8 mils of machine-laid mica and backed with a 2-mil untreated cloth would have a dielectric strength of 500 vpm (mica) times 8 mils, divided by 10 mils (over-all thickness), or 400 vpm.

In regard to mica products and varnished cloth products there are few exact criteria for construction, except that the finished product must meet the commercial performance standards established by NEMA. For example, a 10-mil bias-cut varnished cloth must have a certain minimum tensile strength and a certain minimum dielectric strength, as received and after elongation. One company may use a 6-mil cloth plus 4 mils of varnish, another a 7-mil cloth plus 3 mils of varnish. Both finished products will meet NEMA requirements but will differ in appearance and will handle differently.

As a general rule, the dielectric strength (vpm) of a material drops with an increase in thickness. Obviously, however, this rule does not apply if the increase is obtained by adding high dielectric material:

dielectric strength figures for black varnished bias cloth are higher for the thicker materials than for the thinner. The base cloth apparently is the same for all thicknesses, and the heavier overall thicknesses must have been obtained by using more varnish. This is contrary to the usual practice of insulation manufacturers; ordinarily the base cloth is varied and the varnish film is constant at about 3 mils.

Field coils are not discussed separately, since the materials used to insulate them are similar to the materials used for layer, conductor, and coil insulation of the armature windings.

(a) Conductor Insulation for Single-Strand Conductors and Strand Insulation for Multi-Strand Conductors The main function of strand insulation is to reduce eddy currents. The insulation making contact with the conductor surface is said to be in thermal contact with it (since the conductor will be at the greatest temperature within the machine). Thus the conductor insulation will reach a temperature which will be closer to the hot-spot temperature than any other insulating part. Therefore the most important requirement for the conductor insulation is the ability to withstand the hot-spot temperature developed within the machine. Other requirements are flexibility and thinness. It must withstand abrasion and bending stresses due to winding operations. The selection of a specific material is dependent on the temperature rating and size of the machine.

Though the materials are essentially the same, the reasons for the use of insulation on these parts of the machine are different. Conductor insulation for single-strand conductors provides turn-to-turn insulation, and must withstand the hot-spot temperature as well as the abuse of the handling and winding operations. Strand insulation for multi-strand conductors is used to reduce the flow of eddy currents. A breakdown of the strand-to-strand insulation would be less serious than a breakdown of the turn-to-turn, though some additional local heating would occur at the point of breakdown. The primary requirement is that this insulation withstand hot-spot temperatures.

For both uses, space factor is of primary importance. In most applications any physical separation will suffice to insulate, as long as moisture and chemicals are kept out of the windings. (See Application Chart 1.)

(b) Magnet Wire Selection of the correct type of magnet wire for a particular piece of apparatus becomes increasingly complicated because of the wide variety available — standard and synthetic

APPLICATION CHART 1: CONDUCTOR INSULATION (SINGLE- AND MULTI-STRAND) FOR MACHINES

Rating of 1 — best characteristic; rating of 10 — poorest characteristic but still usable

Material	General Remarks	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Creasing (resistance to)	Tear (resistance to)	Handability	Tensile (Breaking) Strength, lb/in. width		Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to				
														Moisture	Oil	Acid	Base	Solvent
Cotton Plain	Round and rectangular	50-100	7.5 to 3.5	5	4	4	5	3	20		90°C	6	8	9	3	9	9	2
Conventional Varnish		1000-1400	4.5 to 6.0	6	4	4	6	3	40		105°C	6	8	7	4	9	9	4
Rayon Conventional Varnish			2.2 to 2.5	3	4	4	8	3	wrp. 25	fil. 25	105°C	5	8	3	3			6
Asbestos Plain	Cloth	50-100	41.0 to 46.0	8	3	5	7	8	wrp. 70	fil. 32.5	125°C	2	10	10	7	8		7
Glass Plain	Tape	50-100	3.0 to 15.0	7	3	7	1	3	wrp. 135 to 440		300°C+	1	9	1	1	2	4	1
Conventional Varnish	Cloth	1000-1200	3.0 to 15.0	4	3	9	3	3	wrp. 70 to 400		130°C (limited by binder)	4	7	1	1	2	4	1
Silicone Varnish	Round and rectangular	1200-1500	3.0 to 15.0	5	4	9	4	3	wrp. 70 to 400		180°C	2	7	1	10	2	4	10
Mica Conventional Varnish	Applied as tape to rectangular formed conductors. Segment mica shellac	500-1000		3	9	10	2	8	70		180°C	2	7	4	2	6	9	3*
Inorganic Backing	Applied as tape to rectangular formed conductors																	
1) Conventional Varnish	Basis for rating— .002″ glass .004″ mica	900	6.0 to 9.0	5	4	9	3	5	70		130°C (limited by binder)	2	7	2	2	3	3	4
2) Silicone Varnish		600 (at 180°C)	6.0 to 9.0	5	4	9	3	5	70		180°C	2	9	2	10	5		9

* No resistance to alcohol.

enamels; and fibrous coverings such as cotton, paper, rayon, glass, and others; or combinations of the two that are used in magnet wire. The selection of a magnet wire is based upon the following: 1) space factor, 2) electrical properties, 3) mechanical properties, and 4) chemical properties.

In the selection of a magnet wire type, the space consumed by the insulation is one of the most important considerations. The better the space factor is, the smaller the cross-section of the coil, which will give the designer a greater flexibility in the design of a piece of equipment. The cost will depend on the particular case; discussion of this factor is beyond the scope of the present report. Figure 6 compares the space factor for various materials on which data could be obtained. The figures used in plotting the curves were taken from various standard handbooks of some of the larger manufacturers of magnet wire. By space factor is meant the ratio of the total area of copper to the total area of the slot.

The magnet wire must provide the minimum dielectric strength from wire to wire in the coil or winding. The important thing to remember is the amount of damage that can be done to its electrical properties by moisture absorption, acids, alkalis, heat, solvents, and vibration or other harmful effects.

A sacrifice in any of the following qualities of magnet wire may make it ineffective for most modern winding methods such as high-speed or automatic winding machines: 1) resistance to abrasion, 2) resistance to cutting or scraping, 3) adherence to the conductor, and 4) flexibility of the insulation.

Under the heading of chemical properties must be considered the deleterious effects of moisture, water, acids, alkalis, and various solvents which damage the magnet wire and may cause its failure. The synthetic enamels have more chemical stability than the conventional enamels. Although most Class A materials are essentially not affected by most chemicals, they are subject to moisture absorption, which may dangerously reduce their dielectric strength or cause excessive leakage current. Glass insulation withstands these deleterious chemical effects better than most other types of insulating materials.

The chemical and physical effect of heat determines the temperature limitations of magnet wire. The former (or aging of insulation) tends to embrittle or otherwise destroy the insulation and thus determines the life of the insulation at operating temperatures. The latter is caused by extremes of high or low temperatures that result in physical deformation or rupture of the insulation. This factor

Material	Motors and Generators	Transformers	Dielectric Strength, vpm	Build-up, mils*	Abrasion (resistance to)	Flexure (life under)	Elongation
Synthetic Enamel	Single	Formvar and nylon film	3	1 2.0	1-9	Do not think this property applicable to magnet usage. No data on this property; conductor would fail under this test before insulation unless flexing bend is very sharp. In latter event see ratings under bend test	Elongation depends on temper of conductor and on wire size and on large conductors. None of the insulators materially decrease elongation but on smaller wires—glass, silk, nylon, cotton, and felt—will affect elongation downward
	Heavy	Heavy formvar or heavy nylon film	2	2 4.0	1-8		
	Triple	Triple formvar or triple nylon film	1	3 5.1	1-4		
	Quadruple	Quad. formvar or quad. nylon film	1	5 6.8	1-3		
	Single or double nylon	Formvar and yarn or nylon film	6	4	4		
	Single or double silk	Formvar silk or nylon film and silk	4	4	5		
	Single paper	Formvar paper or nylon film paper	7	4	6		
	Single or double cotton	Formvar cotton or nylon film cotton	9	8	1		
	Single or double glass	Formvar glass or nylon film glass	5	6 4.0-9.0	3-4		
	Asbestos	Formvar and asbestos varnish or nylon film asbestos varnish	10	9	7		
	Cellophane	Formvar and cellophane or nylon film and cellophane	7	4	6		
	Cotton over paper	Formvar paper and cellophane or nylon film and paper and cotton	8	7	3		
Conventional Enamel	Single	Enamel	9	1-2 0.8-2.0	4-10		
	Heavy	Enamel	1	1-2 1.5-4.0	3-10		
	Single or double nylon	Enamel and nylon	3	3	3		
	Single or double silk	Enamel and silk	3	3	4		
	Single paper	Enamel and paper	4	3	5		
	Single or double cotton	Enamel and cotton	8	5	1-3		
	Single or double glass	Enamel and glass	2	4	3		
	Asbestos	Enamel and asbestos and asbestos varnish	7	7	5		
	Cellophane	Enamel and cellophane and enamel	5	3	5		
	Cotton over paper	Enamel and paper and cotton	6	6	2		
Bare Copper	Single or double silk	Unsaturated; plain	5-6	1	5-6		
		Saturated; finished	3-4		5-6		
	Single or double nylon		4	1	2		
	Single paper	Unsaturated; plain	7-8	2	7-8		
		Saturated; finished	5-6		3-4		
	Single or double cotton	Unsaturated; plain	9-10	4	5-6		
		Saturated; finished	5-6		3-4		
	Asbestos	Asbestos varnish	2-8	5	1-7		
	Cellophane	Cellophane and enamel	7-8	2	5-8†		
	Cellulose acetate		5-6		7-8†		
	Cotton over paper	Paper and cotton	5	6	4		

* Rated on basis of space factor (or coils moved) of the wire; the thinner the insulation the better the space factor.

Material	Motors and Generators	Transformers	Dielectric Strength, vpm	Build-up, mils*	Abrasion (resistance to)	Flexure (life under)	Elongation	Bend (continuity of insulation under)	Handability	Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to Moisture	Resistance to Oil	Resistance to Acid	Resistance to Base	Resistance to Solvent	Stripping (ease of) Chem.	Stripping (ease of) Mech.
Synthetic Enamel	Single	Formvar and nylon film	3	1 2.0	1-9	Do not think this property applicable to magnet usage. No data on this property; conductor would fail under this test before insulation unless flexing bend is very sharp. In latter event see ratings under bend test	Elongation depends on temper of conductor and on wire size and on large conductors. None of the insulators materially decrease elongation but on smaller wires—glass, silk, nylon, cotton, and felt—will affect elongation downward	1	1	3 105°C	2-4	1	1-4	All constructors are resistant to and unaffected by mineral oils and no data on relative resistance	4	3-5	4-6	1-4	1
	Heavy	Heavy formvar or heavy nylon film	2	2 4.0	1-8			1	1	3 105°C	2-4	2	1-3		3-4	3	3-5	2	3
	Triple	Triple formvar or triple nylon film	1	3 5.1	1-4			1	1	3 105°C	2-4	3	1-2		2-4	2-3	2-4	3	4
	Quadruple	Quad. formvar or quad. nylon film	1	5 6.8	1-3			1	1	3 105°C	2-4	4	1		1-4	1-3	1-3	4-5	5
	Single or double nylon	Formvar and yarn or nylon film	6	4	4			2	2	2	3	5	3		5	4	2		6
	Single or double silk	Formvar silk or nylon film and silk	4	4	5			2	2	2	3	5	3		6	4	1		5
	Single paper	Formvar paper or nylon film paper	7	4	6			3	3	2	4	5	4		7	6	1		3
	Single or double cotton	Formvar cotton or nylon film cotton	9	8	1			2	2	2	5	6	4		7	6	1		2
	Single or double glass	Formvar glass or nylon film glass	5	6 4.0-9.0	3-4			2-3	4-6	1 130°C	1-2	3-5	2-4		2-3	3-7	1-4		3-7
	Asbestos	Formvar and asbestos varnish or nylon film asbestos varnish	10	9	7			5	5	1	1	7	5		3	8	1		5
	Cellophane	Formvar and cellophane or nylon film and cellophane	7	4	6			3	2	2	5	5	5		7	6	1		3
	Cotton over paper	Formvar paper and cellophane or nylon film and paper and cotton	8	7	3			4	3	2	4	6	5		7	6	1		3
Conventional Enamel	Single	Enamel	9	1-2 0.8-2.0	4-10			1-3	1	3	6	1-2	1-9	5	3-5	4-5	5-8	1	1
	Heavy	Enamel	1	1-2 1.5-4.0	3-10			2	1	3	5-6	2-3	1-3	4	1-4	1	4-8	3	2
	Single or double nylon	Enamel and nylon	3	3	3			3	2	2	4	3	3	2	5	2	3		6
	Single or double silk	Enamel and silk	3	3	4			3	2	2	3	3	3	2	5	2	3		5
	Single paper	Enamel and paper	4	3	5			3	3	2	2	3	5	2	6	3	3		4
	Single or double cotton	Enamel and cotton	8	5	1-3			2-5	1-4	2	5-6	4-5	5-6	3-6	5-6	3	3-6		1-3
	Single or double glass	Enamel and glass	2	4	3			4	4	1	1	3	2	1	2	5	2		7
	Asbestos	Enamel and asbestos and asbestos varnish	7	7	5			6	5	1	1	6	8	1	4	5	All are resistant to organic solvents		5
	Cellophane	Enamel and cellophane and enamel	5	3	5			3	2	2	5	3	6	3	6	3			4
	Cotton over paper	Enamel and paper and cotton	6	6	2			5	3	3	4	5	7	2	6	3			4
Bare Copper	Single or double silk	Unsaturated; plain Saturated; finished	5-6 3-4	1	5-6 5-6			1	1	90°C 105°C	2	1	9-10 5-6	See note above	3	1			2
	Single or double nylon		4	1	2			1	1	2	2	2	3		2	1			
	Single paper	Unsaturated; plain Saturated; finished	7-8 5-6	2	7-8 3-4			4	2	90°C 105°C	3	3	9-10 5-6		4	2			6
	Single or double cotton	Unsaturated; plain Saturated; finished	9-10 5-6	4	5-6 3-4			2	1	90°C 105°C	4	4	9-10 5-6		4	2			1
	Asbestos	Asbestos varnish	2-8	5	1-7			6	5	1	1	7	2-8		1	5			7
	Cellophane	Cellophane and enamel	7-8	2	5-8†			3	2	2	5	3	5-8		4	3			5
	Cellulose acetate		5-6		7-8†					105°C			5-6						
	Cotton over paper	Paper and cotton	5	6	4			3	3	2	3	5	7		4	2			4

* Rated on basis of space factor (or coils moved) of the wire; the thinner the insulation the better the space factor.
† Very resistant to petroleum and coal tar solvents. Soluble in most lacquer solvents.

determines the extremes of temperatures that may be held before destroying the insulation without actually aging or embrittling it. (See Application Chart 2.)

(c) Conductor Insulation for Multi-Strand Conductor In the voltage range being considered in this report, the voltage stress on the conductor insulation is not high enough to present any problem as

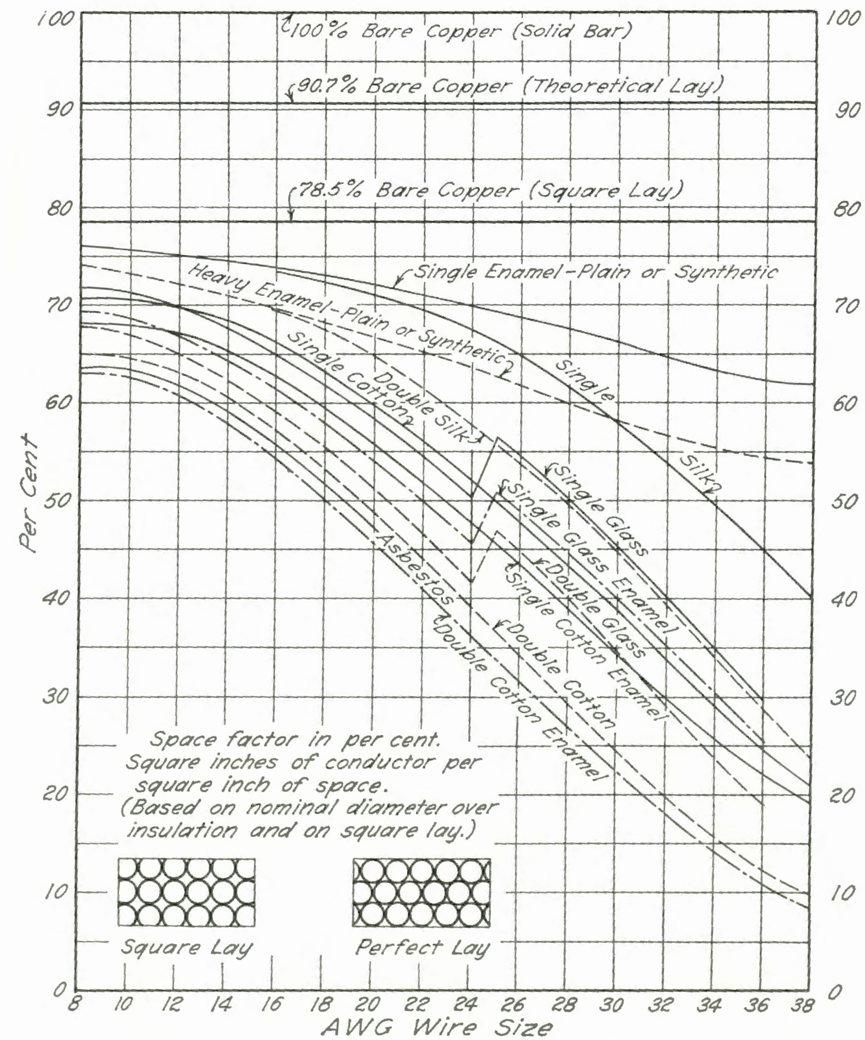

FIG. 6. SPACE FACTOR CHART

Application Chart 3: Coil Wrappers for Machines

Rating of 1 — best characteristic; rating of 10 — poorest characteristic but still usable

Material	General Remarks	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Creasing (resistance to)	Tear (resistance to)	Handability	Tensile (Breaking) Strength, lb/in. width	Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to: Moisture	Oil	Acid	Base	Solvent
Cambric Black Varnish	AC motor and generator	1000-1250	7.0 to 12.0	5	4	3	6		57-60	105°C	5-6	8	6	5	9	9	6
Rayon Yellow Varnish			2.2 to 2.5	3	4	4	8	3	wrp. 25 / fil. 25	105°C	5	8	3	3			6
Silk Conventional Varnish		1000-1900	4.0 to 5.0	3	4	4	8	3	20	105°C	5	8	3	2			6
Asbestos Plain	Cloth	50-100	41.0 to 46.0	8	3	5	7	8	wrp. 70 / fil. 32.5	300°C	2	10	10	7	8		7
Glass Plain	Cloth	50-100	3.0 to 15.0	7	3	7	1	3	70-450	300°C	1	9	1	1	2	4	1
Conventional Varnish		1000-1200	3.0 to 30.0	4	3	9	2-3	3-7	70-550	130°C (limited by binder)	1-4	5-7	1	1	2	4	1
Silicone Varnish	Cloth	1000-1500	4.0 to 20.0	5	4	9	2-4	3-8	70-450	180°C	2	5-7	1	10	2	4	10
Mica Conventional Varnish	AC motor and generator. Class H; a paper-mica-paper laminate	1000	5.0 to 15.0	10	10	9	10			180°C	2	7	4	2	6	9	3
Inorganic Backing	AC motor and generator. Class H; mica-glass laminate																
1) Conventional Varnish	Basis for rating— 0.002 glass 0.004 mica	900	6.0 to 15.0	5	3-4	3-9	3	5		130°C	2	7	2	2	3	3	4
2) Silicone Varnish		600 (at 180°C)	6.0 to 15.0	5	4	9	3	5		180°C	2	9	2	10	5		9

Application Chart 4: Coil Tapes

Rating of 1 — best characteristic; rating of 10 — poorest characteristic but still usable

Material	General Remarks	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Creasing (resistance to)	Tear (resistance to)	Handability	Tensile (Breaking) Strength, lb/in. width	Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to: Moisture	Oil	Acid	Base
Cotton Plain	AC and DC tapes ½, ¾″ wide		5.0 to 7.0	6	4	4	6		40	105°C	5	8	7	4	9	9
Conventional Varnish	Yellow varnish	1000-1400	4.5 to 16.0	6	4	4	6	3	40-60	105°C	5	5-7	7	4	9	9
Silk Conventional Varnish		1000-1900	4.0 to 5.0	3	4	4	8	2	20	105°C	5	5-7	3	2		
Glass Plain	AC and DC tapes ⅜ to 1½″ wide	50-100	3.0 to 25.0	7	3	7	1	3	135-300	280°C	1	9	1	1	2	4
Conventional Varnish	Yellow	1000-1200	4.0 to 30.0	4	3	9	2-3	3-7	70-550	130°C (limited by varnish)	1-4	5-7	1	1	2	4
Silicone Varnish		1000-1500	4.0 to 20.0	5	4	9	2-4	3-8	70-450	180°C	2	5-7	1	10	2	4
Mica Conventional Varnish	Segment mica	1000		3	9	10	2	8		180°C	2	7	4	2	6	9
Organic Backing	AC and DC tapes; paper, mica, paper	300-500	3.0 to 12.0	6-9	5-9	6-10	7-8			105 to 130°C	4-8	8	8	6	9	
Inorganic Backing	Paper, mica, paper	900	6.0 to 9.0	5	4	9	3	5		180°C (limited by binder)	2	7	2	2	3	3
1) Silicone Varnish	Basis for ratings— 0.002″ glass 0.004″ mica										2	9	2	10	5	
2) Conventional Varnish																

far as dielectric strength is concerned. The main problem is to obtain the necessary mechanical strength to withstand the bending, abrasion, and compressive stresses due to winding and forming operations. If the voltage stresses are low enough, instead of taping the entire conductor the use of a mica separator between conductors in the slot portion is allowed. Here again, the choice of material to be used is dependent upon the temperature rating and the size of the machine. (See Application Chart 1.)

(d) Coil Insulation (Wrapper and Tape) The coil insulation must be able to withstand the electric potential applied to the coil plus any additional voltages induced in the coil by transient conditions in the armature. It must provide the necessary ground insulation for the coil and must withstand pounding, creasing, and bending. It should be moisture- and chemical-resistant if the machine is to be operated in either a humid or a corrosive atmosphere. Size, voltage, and other design considerations also enter into the selection of the insulation for the coil. (See Application Charts 3 and 4.)

(e) Phase Insulation Since the greatest voltage stress occurs on the phase insulation, it must possess a greater dielectric strength than insulation for other portions of the machine. Since the greatest mechanical stresses also occur on it, it must further have good mechanical strength. It must, thirdly, have moisture- and chemical-resistant qualities. Selection of an insulation for this part depends on the usual design factors. As regards fractional-horsepower machines, paper plays the greatest part in the insulation for phase, layer, and slot liner insulation. (See Application Chart 5.)

(f) Layer Insulation for d-c and a-c Machines The main purpose of the layer insulation is to provide the necessary dielectric strength between layers. Some a-c machines have two phases within the same slot, and so the voltage gradient may be high. The type of material used depends on the size, temperature, and kva rating of the machine. (See Application Chart 5.)

(g) Slot Liners Even with maximum precaution in assembling and in smoothing with a file, the sides of the slots may be rather rough. An insulating material must be utilized that has the mechanical strength necessary to withstand abrasion.

Slot liners can be made with a Class B mica paper combination. The paper is used solely for protecting the mica during the manufacturing process—keeping it from splitting after it is in the slot, while the coils are slipped in. The paper should be very thin, so that it does not matter whether it deteriorates while the generator is in use.

The two types of paper particularly suited for this job are rag and fish papers. Rag paper is rather tough and abrasion-resistant. Fish paper is dense, tough, hard, and not affected by oil; withstands sharp bending; and has a good dielectric strength when dry. These papers are often used in combination with varnished cambric for Class A. The varnished cambric provides the insulation or dielectric properties, and the fish or rag paper acts as a mechanical safeguard against the laminations; the coil wires rest against the varnished cambric.

Mica alone or faced with asbestos or glass fiber may be used in a Class B system. For Class A, paper alone or composite paper and other Class A materials may be used. In the Class H range there exists the silicone-glass-mica combination. (See Application Chart 6.)

(h) Slot Wedges The slot wedges of a Class A insulated machine usually consist of a formed fibrous material. These wedges perform very well when operation is restricted to Class A temperatures, but any excessive heating will cause the wedges to split and crack and eventually to work their way out of the slot. To make the coil more secure and tight-fitting, and to provide a sliding surface for the wedge, strips of insulating materials are often placed between the wedge and coil. (See Application Chart 7.)

(i) Laminates Laminates can be obtained in a wide range of properties, depending upon the requirements of the specific application. For a purely structural purpose—slot sticks, end laminates, coil spacer bars, terminal strips—good mechanical properties are required but average electrical properties would be satisfactory. For applications such as coil forms, vacuum tube bases, and high frequency equipment, the important considerations which might mean sacrificing some mechanical strength to obtain them are dielectric strength, insulating resistance, and loss factor. The properties of the finished laminate depend on the resin and reinforcing medium used.

The reinforcements commonly used for laminates are paper, cotton, asbestos, glass, and nylon. The paper used in laminates must be uniform in basic weight and thickness. The Kraft papers impart good strength; the alpha cellulose, good strength coupled with good electrical properties. (See Detailed Chart—Papers.)

The resins commonly used in laminates are phenolics, melamines, polyesters, etc. The resin and base are so chosen that the combinations will give the properties desired in the end product. A chart is given to aid in selecting a laminate for the particular application involved.

When the coil is bent at the ends of the armature, any sharp corners or burrs on the iron will damage the insulation; therefore,

Application Chart 5: Phase and Layer Insulation for Machines

Rating of 1 — best characteristic; rating of 10 — poorest characteristic but still usable

Material	General Remarks	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Creasing (resistance to)	Tear (resistance to)	Handability	Tensile (Breaking) Strength, lb/in. width	Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to Moisture	Resistance to Oil	Resistance to Acid	Resistance to Base
Cotton Conventional Varnish	AC motor and generator random only	1000-1400	4.0 to 25.0	3-6	3-4	3-4	3-6	3	40	105°C	5-6	8	7	4	9	9
Paper Conventional Varnish	Kraft	160	4.7 to 5.3	9	4	5	4	3	MD-CMD 250-260	105°C	7	5	8	4	9	9
Rayon Conventional Varnish		1000-1200	2.2 to 15.0	3-7	4	4	8	3-5	wrp. 25 / fil. 25	105°C	5	8	3	3		
Pressboard	50-50 fuller board	400	25.0 to 62.0	9	4	3	5	9		105°C	5	7	10	8	10	10
Silk Conventional Varnish		1400-1900	4.0 to 5.0	3	4	4	8	3	20	105°C	5	8	3	2		
Canvas Conventional Varnish		400-800	12.0 to 30.0	3	3	5	2	4	75 to 120	105°C	5	8	8	8		
Asbestos Unvarnished	Cloth	50-100	41.0 to 46.0	8	3	5	7	8	30 to 40	130°C	2	10	10	7	8	
Glass Unvarnished		50-100	9.0 to 11.0	7	3	7	1	3	70-450	300°C	1	9	1	1	2	4
Conventional Varnish	AC motor and generator random only	1000-2000	3.0 to 30.0	4	3	9	2-3	3-7	70-550	130°C (limited by varnish)	1-4	5-7	1	1	2	4
Silicone Varnish		1000-1500	5.0 to 20.0	5	4	9	2-4	3-8	70-450	180°C	2	5-7	1	10	2	4

Application Chart 5: Phase and Layer Insulation for Machines (Concluded)

Rating of 1 — best characteristic; rating of 10 — poorest characteristic but still usable

Material	General Remarks	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Creasing (resistance to)	Tear (resistance to)	Handability	Tensile (Breaking) Strength, lb/in. width	Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to Moisture	Resistance to Oil	Resistance to Acid	Resistance to Base
Mica Unbacked	Segment mica shellac	1000		3	9	10	2	8		180°C	2	7	4	2	6	9
Organic Backed Conventional Varnish		600	7.0 to 18.0	5	4-7	9	3	5-8		105°C (limited by varnish and binder)	2	7	2	2	3	3
Inorganic Backed 1) Conventional Varnish	Basis for ratings: .002 glass .004 mica	600-900	5.0 to 35.0	5	4-7	9	3	5-8		130°C (limited by binder)	2	6-7	2	2	3	3
2) Silicone Varnish	Basis for ratings: .002 glass .004 mica	600-900	3.5 to 12.0	5	4	9	3	5		180°C	2	9	2	10	5	
Laminates	Phenolic laminated paper. See laminate chart	700	10.0 to 250.0	4	6	9		7-8	5	105°C	5	3-5	4	3	3	3

HART 5. SLOT LINERS FOR MACHINES

Rating of 1 — best characteristic; rating of 10 — poorest characteristic but still usable

Material	General Remarks	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Creasing (resistance to)	Tear (resistance to)	Handability	Tensile (Breaking) Strength, lb/in. width	Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to Moisture	Resistance to Oil	Resistance to Acid	Resistance to Base	Resistance to Solvent
Cotton Conventional Varnish		1000-1400	4.0 to 25.0	6	3-4	3-4	5-6	3	40	105°C	6	5-7	7	4	9	9	4
Paper Conventional Varnish	Kraft; small motors practically all of it; DC motor and Generator "A" insulations. See detailed chart	150	10.0	5-9	4-7	5-9	4-9	3-10	250-260	105°C	5-7	5-10	8	4	9	9	4-9
Rayon Conventional Varnish		1000-1200	2.5 to 22.0	3	4	4	8	3	wrp. 25; fil. 25	105°C	5	8	3	3			6
Silk Conventional Varnish		1200-1900	4.0 to 5.0	3	4	4	8	3	20	105°C	5	8	3	2			6
Asbestos Unvarnished	Cloth	1000-1200	41.0 to 46.0	8	3	5	5	8	wrp. 70; fil. 32.5	125°C	2	10	10	7	8		7
Glass Conventional Varnish		1000-1200	3.0 to 30.0	4	3	9	3	5	wrp. 70 to 550	130°C (limited by varnish)	4	7	1	1	2	4	1
Silicone Varnish		1000-1500	4.0 to 20.0	5-6	4	9	3-4	5	wrp. 70 to 400	180°C+	1-2	7	1	10	2	4	10
Mica Unbacked	Segment mica shellac	1000		3	9	10	2	8		180°C (limited by binder)	2	7	4	2	6	9	3*
Organic Backed Conventional Varnish	DC motor and generator (B insulation with thin paper)	600-900	7.0 to 20.0	5	4	9	3	6		105 to 130°C	3	7	2	2	3	3	4
Inorganic Backed 1) Conventional Varnish	Basis for rating— .002 glass .004 mica	600-900	5.0 to 35.0	5	4	9	3	5-6			2	7	2	2-3	3-5	3-5	4-6
2) Silicone Varnish	DC motor and generator (H insulation)	600 (at 180°C)	3.5 to 12.0	5	4	9	3	5		180°C	2	9	2	10	5		9

* No resistance to alcohol.

Rating of 1 (best) to 10

Material	General Remarks	Dielectric Strength, vpm: Short Time	Dielectric Strength, vpm: Step by Step	Insulation Resistance Megohms	Power Factor at 10^6 cps as Received	Dielectric Constant at 10^6 cps as Received	Loss Factor	Arc Resistance, sec	Tensile Strength, p.s.i.: LW	Tensile Strength, p.s.i.: CW	Compress. Strength (flat), p.s.i.	Flex. Strength: LW	Flex. Strength: CW	Impact Strength: Face	Impact Strength: Side	Hardness, Rockwell	Bonding Strength, lb	Cold Flow 0-50°	High Temp.	Ther. Blister Cond. Temp., C	Operating Temperature	Moisture Absorption, % in 24 hr	Acid Resistance	Base Resistance
Paper Phenolic	X XP XX XXX XXP XXXP	1 400 to 600	1 250 to 600	3 90 to 5800	5 20.0 to 80.0	5 3.6 to 6.50	5 .08 to .27	10 .4 to .16	8 9000 to 16 000	8 7500 to 12 000	6 26 000 to 42 000	5 13 000 to 30 000	5 12 500 to 22 000	5-10	9-10	100 to 120	2 900 to 1200	1-3	3-4	4 230 to 260	3	3 0.3 to 9.0	3	4
Melamine	MX MXX	6 400 to 700	6 200 to 450	2 50 to 200	8 35.0 to 45.0	8 6.75	9 .29 to .37	2 70 to 100	9 20 000	9 15 000	6 30 000 to 48 000	6 23 000 to 25 000	6 18 000 to 19 000	9-10	10	125	2 900 to 1000	5-8	5-8	3 225 to 250	3	7 2.4 to 3.5	3	2
Cotton Cloth Phenolic	C CF CFL CV CE LELDC	4 150 to 600	4 120 to 400	7 10 to 100	7 .02 to 100.0	7 4.5 to 7.0	7 .22 to .7	10 4	6 9000 to 14 500	6 7500 to 12 000	4 30 000 to 44 000	5 20 000 to 23 500	5 16 000 to 22 000	4-6	4-7	70 to 120	1 1900 to 2200	1-5	3-5	3 210 to 250	3	6 0.3 to 9.0	3	4
Melamine		6 320 to 370	6 280 to 320	2	8 .031 to .047	8 6.2 to 10.0	8	2 120 to 1.75	5	5	4 33 000 to 46 000	5 14 000 to 28 000	5	5	5	110 to 120	1	6	6	2	2	6 0.4 to 1.3	3	4
Polyester		600	540			2.0	.05 to .03	90	7700		16 600	13 300				96						0.84		
Cotton Felt Phenolic		3	3	5	6	6	6	10	6	6	5	5	5	3	3		1	1-4	3-5	4	4	5		
Glass Cloth Phenolic	(GB-128D) G- (GB-261D)	4 300 to 650	4 360 to 390	10 25 to 500	5 10.0 to 30.0	5 3.7 to 6.0	5 .046 to .13	10 4.15	15 000 to 24 000	11 000 to 15 000	39 000 to 47 000	21 000 to 22 000	19 000	1-3	1-3	95 to 110	2 1200 to 1500	1-2	3-5	270	5 (140°C)	1 0.3 to 0.6	3	4 depends on resins used
Melamine	(GB-128M) G-	5 350 to 520	5 320 to 380	10 50	8 11.0 to 1.40	8 6.9 to 7.7	8 .094 to .12	2 180 to 125	25 000 to 37 000	22 000 to 33 000	30 000 to 97 000	40 000 to 53 000	38 000 to 45 000	1-3	1-3	120	3 900 to 1750	5-8	6-8	270	3 (160°C)	1 0.45 to 0.9	3-7	3-5
Polyester		600	540			2.0	.05 to .03	15-90	20 000 to 35 000		20 000 to 23 000	37 900 to 40 000				110 to 114		6-8	6-8					
Silicone	Continuous filament	10 250 to 300	10 50 to 350	10 3000	1 1.2 to 1.7	1 2.8 to 4.3	1 .0048	1 228	8 19 000	8 17 000	35 000 to 75 000	32 000 to 44 000	30 000 to 37 000	2-5	2-5 2.7	100	5 900 to 1100	1-4	1-2	260	1 (250°C)	1 0.15 to 0.65	1-7	9-10
Glass Mat Phenolic	GM-4	3 600	3 400	9 175	5 .013	5 3.75	5 .049	10 10	6 6500	6 6200	29 000	6 9000	4 8500	4-6 8	4-6 7.5	.85	1 900	1 1-3	3-5	230	(140°C)	1 0.23		depends on resins used
Melamine	T36 Type Glass Mat (½K)	5 380	5	9 450 70V (after 96 hr at 95% RH) 9	9 .015	8 7.2	8 .11	2 132	6 19 800	6 19 800	18 200 edge- wise	6 32 000	33 000	5-8 7	5-8 7		2 900			250	(160°C)	1 2.0 (18 K)	3	3
Polyester*		600	540			2.0	.05 to .07	90	19 000 (93°C)		3900 (93°C)	1300 (93°C)						6-8	6-8					
Silicone		9	9	9	1	1	1	1	7	7	7	7	7	4	4		3	1-4	1		(250°C)	1	1	10
Nylon Cloth Phenolic	MEC-1	5 475	5 375	1 30 000	2 14.0 to 30.0	2 3.5 to 3.9	2 .105	10 15	7 9500	7 3400	5 31 000 to 35 000	6 32 000	6 21 000	1 3	1 5	10	2 700	3 1-2	3-5		(120°C)	1 0.2 to 0.35	3	4
Melamine	MEC-2	450	250	200	.07	3.9	.273	70	14 000	13 000	4000	27 000	24 000	2.5	3	110	500	6-8	6-8			2.0		
Asbestos Paper Phenolic*	A	5 100 to 200	5 60 to 220	7	.115 to .12	5.2 to 7.5	.6 to 1.12	10 4	7 11 000 to 13 000	8 7000 to 10 000	5 36 000 to 41 000	7 18 000 to 25 000	8 16 000 to 18 000	6	7-8	100 to 110	6 900	1	2	2-5 230	2-5	3 0.4 to 2.0	3	4

Melamine	(GB-128M) G-	5 350 to 520	5 320 to 380	10 50	8 11.0 to 1.40	8 6.9 to 7.7	8 .094 to .12	2 180 to 125	25 000 to 37 000	22 000 to 33 000	30 000 to 97 000	40 000 to 53 000	38 000 to 45 000	1-3	1-3	120	3 900 to 1750	5-8	6-8	270	3 (160°C)	1 0.45 to 0.9	3-7	3-5
Polyester		600	540			2.0	.05 to .03	15-90	20 000 to 35 000		20 000 to 23 000	37 900 to 40 000				110 to 114		6-8	6-8					
Silicone	Continuous filament	10 250 to 300	10 50 to 350	10 3000	1 1.2 to 1.7	1 2.8 to 4.3	1 .0048	1 228	8 19 000	8 17 000	35 000 to 75 000	32 000 to 44 000	30 000 to 37 000	2-5	2-5 2.7	100	5 900 to 1100	1-4	1-2	260	1 (250°C)	1 0.15 to 0.65	1-7	9-10
Glass Mat Phenolic	GM-4	3 600	3 400	9 175	5 .013	5 3.75	5 .049	10 10	6 6500	6 6200	29 000	6 9000	4 8500	4-6 8	4-6 7.5	.85	1 900	1 1-3	3-5	230	(140°C)	1 0.23		de- pends on resins used
Melamine	T36 Type Glass Mat (⅛K)	5 380	5	9 450 70V (after 96 hr at 95% RH) 9	9 .015	8 7.2	8 .11	2 132	6 19 800	6 19 800	18 200 edge- wise	6 32 000	33 000	5-8 7	5-8 7		2 900			250	(160°C)	1 2.0 (18 K)	3	3
Polyester*		600	540			2.0	.05 to .07	90	19 000 (93°C)		3900 (93°C)	1300 (93°C)						6-8	6-8					
Silicone		9	9	9	1	1	1	1	7	7	7	7	7	4	4		3	1-4	1		(250°C)	1	1	10
Nylon Cloth Phenolic	MEC-1	5 475	5 375	1 30 000	2 14.0 to 30.0	2 3.5 to 3.9	2 .105	10 15	7 9500	7 3400	5 31 000 to 35 000	6 32 000	6 21 000	1 3	1 5	10	2 700	3 1-2	3-5		(120°C)	1 0.2 to 0.35	3	4
Melamine	MEC-2	450	250	200	.07	3.9	.273	70	14 000	13 000	4000	27 000	24 000	2.5	3	110	500	6-8	6-8			2.0		
Asbestos Paper Phenolic*	A	5 100 to 200	5 60 to 220	7	.115 to .12	5.2 to 7.5	.6 to 1.12	10 4	7 11 000 to 13 000	8 7000 to 10 000	5 36 000 to 41 000	7 18 000 to 25 000	8 16 000 to 18 000	6	7-8	100 to 110	6 900	1	2	2-5 230	2-5	3 0.4 to 2.0	3	4
Melamine	MA	100 to 150	60 to 80	5	.11 to .22	8.0 to 9.6	9	.80	10 000	6000	27 000 to 47 000	17 000	13 000	6-7	8	115	900	3	3	230	2-3	5 1.0 to 4.2	2	1
Polyester		5	5	5				3	7	8	5	7	8	6			6	3	3	2-3	1-3	2		
Silicone		10	10	10				3	9	10	5	9	10	7	8		7	2	1	1-3	2-5	3 0.3 to 3.0	3	4
Asbestos Cloth Phenolic	AA	7 60 to 150	7 45 to 125	9	.15 to .44	6.6 to 7.5	1.12 to 2.99	10 4	6 10 000 to 12 000	7 6500 to 11 000	5 18 000 to 49 000	6 19 000 to 25 000	7 15 000 to 24 000	4-6	4-7	106 to 110	5	1	2	2-5 270	2-3	3-6	2	1
Melamine		7 40 to 100	7	9				4	6 9000 to 12 000	7	5 25 000 to 50 000	6 20 000 to 24 000	7	6	7	110 to 115	5	3 3	3 3	2-3				
Polyester		600	540			2.0	.05 to .03	90	7100		18 500	31 000				102						0.56		
Silicone		10 50 to 150	10 50 to 100	10				4	8	9	5 40 000 to 50 000	8 12 000 to 16 000	9	7	8		6	2	1	1-3	1-2	3 1.0 to 1.5	3	4
Asbestos Felt Phenolic	FA-72	70	50					4	21 000	17 000	16 000 to 52 000	38 000	27 000	4	6	115	1400	1	2	225		0.4 to 1.0	3	4
Melamine																		3	3					
Polyester*																		3	3					
Silicone																		2	1					

* One of the more commonly used Polyesters was used for comparison basis.

end laminations are used to provide the mechanical protection at these points for the coils. It must be strong and heat-resistant. (See Application Chart 7.)

(j) Lead Wire For lead and intercoil connections there exist a variety of tapes and sleeving. Choice depends on the requirements that must be met. The following factors are important: degree of flexibility, dielectric strength requirements, maximum temperatures, minimum temperatures, types of solvent that might make contact. (See Appendix B, Table 8.)

Selection of binding or typing cord is dependent upon size and other design requirements. Cotton or linen may be used for Class A operation. If the application is Class B, asbestos or glass fiber should be used; the cordage may be plain or treated, depending on requirements of the applications. The treatment determines the slippage and knot strength. Class H operation would demand glass fiber or asbestos. (See Application Charts 8 and 9.)

(k) Commutator Insulation If a given machine is so altered as to permit increased load by using high-temperature insulation, the commutating duty increases but the commutating capacity is relatively unchanged. The rating of a d-c motor is dependent on the permissible temperature rise of the insulation or on the permissible commutating duty, whichever is lower. In a well designed machine the ratings by these two criteria are approximately equal.

A higher operating temperature of the commutator results in a somewhat higher bar-to-bar roughness. More than any other feature, the ability of the commutator to go through a temperature cycle insures good operation. The insulation must be temperature-resistant (mechanically and electrically) and moisture-resistant.

Though many materials have been tried for commutator insulation none have been nearly as successful as mica. If soft mica is used it will wear at approximately the same rate as the copper bars.

(l) Field Pole Protection The requirements for field pole insulation are mainly mechanical, since the voltage from the field coils to ground seldom exceed about 250 volts. Because most a-c machines are designed with the field structure as the rotor, there are large centrifugal forces on the field coils of the machines, as well as forces due to starting and stopping. The mechanical properties essential are resistance to abrasion and repeated compression. Even stationary field coils experience forces, and also changes in forces, when the voltage is first applied. (See Application Chart 12.)

Application Chart 8: Lead Wire (Stranded Cable)

Rating of 1 — best characteristic; rating of 10 — poorest characteristic but still usable

Material	Insulation Resistance	Abrasion (resistance to)	Flexure (life under)	Bend (continuity of insulation under)	Stripping	Maximum Operating Temperature	Thermal Aging	Resistance to: Moisture	Oil	Acid	Solvent
Plastic or Rubber											
Plain	2	2	1	1	3	5	3	2	4	2	1
Cotton Braid and Lacquer	4	1	2	2	1	4	4	3	2	3	3
Rayon Braid and Lacquer	3	4	3	3	2	4	4	4	3	4	4
Glass Braid and Lacquer	1	3	4	4	4	3	3	1	1	1	2
Cotton											
Cambric and Cotton Braid	3	2	3	4	4	4	4	4	4	6	4
Multiple Cotton Braid	6	5	4	3	5	5	10	10	10	10	6
Asbestos											
Cambric and Outer Braid of Asbestos	4	2	2	4	8	2	2	6	6	6	3
Glass											
Conventional Varnish, Outer Braid of Asbestos	3	2	2	4	7	2	2	4	5	5	3
Silicone Varnish, Outer Braid of Glass	3	5	6	5	4	1	1	6	5	5	3
Silicone Rubber Outer	2	5	6	5	4	1	1	5	4	5	4
Fibrous Wraps											
Nylon Serve or Braid (conventional varnish, shellac)	5	2	4	4	5	3	3	2	2	4	2
Rayon Serve or Braid (conventional varnish, shellac)	4	4	5	5	6	5	4	5	5	6	3
Glass Serve or Braid (conventional varnish, shellac)	3	3	5	5	5	2	2	2	4	6	3

Application Chart 9: Tubing

Rating of 1 — best characteristic; rating of 10 — poorest characteristic but still usable

Material	General Remarks	Dielectric Strength, vpm	Abrasion (resistance to)	Flexure (life under)	Bend (continuity of insulation under)	Handability	Maximum Operating Temperature	Thermal Aging	Heat Endurance	Flame Resistance	Resistance to: Moisture	Oil	Acid	Solvent
Synthetics														
Extruded Plastic Tubing	Vinyl type—some types available temperature up to 125°C	1090/28°C	2	1	1	1	105°C	1-4	1-5	Self-extinguishing	2	2	2	3
Fibrous														
Glass	Varnished; standard NEMA grades		2	3-5	3-5	2	130°C	2	2	Good	2	2	2	2
Cotton	Varnished; standard NEMA grades		2	3-5	3-5	2	105°C	6	6	Fair	5	4	6	5
Rayon	Varnished; standard NEMA grades		2	3-5	3-5	2	105°C	4	5	Fair	3	3	6	5

Application Chart 10: Banding Wire Insulation — Coil

Rating of 1 — best characteristic; rating of 10 — poorest characteristic but still usable

Material	General Remarks	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Toughness	Tear (resistance to)	Tensile (Breaking) Strength, lb/in. width	Maximum Operating Temperature	Thermal Aging	Resistance to Moisture	Resistance to Oil	Resistance to Acid	Resistance to Base	Resistance to Solvent
Pressboard	Rag and Kraft, pretreated	400	60.0	9	4	7	4	7	105°C	5	9	5	10	10	8
Asbestos															
Unvarnished	Cloth	50-100	26.0 to 31.0	8	3	9	7		130°C	2	10	7	8		7
Conventional Varnish	Cloth	50-100	60.0	3	3		4	3	130°C	4	5	3	4	4	3
Silicone Varnish			60.0	3	3		4	3	180°C	2	4	8	4	4	4
Glass															
Conventional Varnish		1000-1200	10.0 to 30.0	2-4	2-3	3	2-9	250 to 550	130°C	4	1-3	1-2	2	4	1-3
Silicone Varnish		1000-1500	10.0 to 20.0	2-5	2-4	3-4	2-9	250 to 400	180°C	2	1-2	8-10	2	3-4	4-10
Mica															
Unbacked	Under asbestos for some Class B segment mica	1000-1500	30.0	3-5	9	8	2		180°C+	2	4	2	6	4	3*
Organic Backed Conventional Varnisb		900	7.0 to 30.0	5	4		9		105-130°C	3	2	2	3	3	4
Inorganic Backed 1) Conventional Varnish	Basis for rating— .002 glass .004 mica	900	10.0 to 35.0	5	4	4	3		130°C	2	2	2	3	3	4
2) Silicone Varnish	Under asbestos for Class H	600	10.0 to 20.0	5	4	4	3		180°C	2	2	10	5		9

* No resistance to alcohols.

Application Chart 11: Banding Wire Insulation — Core

Rating of 1 — best characteristic; rating of 10 — poorest cbaracteristic but still usable

Material	General Remarks	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Toughness	Tear (resistance to)	Tensile (Breaking) Strength, lb/in. width	Maximum Operating Temperature	Thermal Aging	Resistance to Moisture	Resistance to Oil	Resistance to Acid	Resistance to Base	Resistance to Solvent
Paper Conventional Varnish	Small DC machine. Class A insulation. Thin papers treated both sides, e.g., 10.0 to 20.0 mils	400-900	0.25 to 500.0	6	6		7	6	105°C		6	6	7	5	4
Pressboard	Basis for rating is 125.0 mils thickness	150-200	7.0 to 500.0	7	5		6	7	105°C	5	8	7	6	7	5
Canvas	Untreated	50-100	24.0	5	4		5	5	105°C		7	5	5	6	5
Asbestos															
Unvarnished	Cloth	50-100	45.0 to 50.0	4-8	3	8	3-7	wrp. 70 / fil. 32.5	130°C	2	9-10	4-7	3-8	1	1-7
Conventional Varnish	Small DC machine. Class B insulation	50-100	30.0	3	3		4	3	130°C	4	5	3	4	4	3
Silicone Varnish				3	3		4	3	180°C	2	4	8	4	4	4
Glass															
Conventional Varnish		1000-1200	3.0 to 30.0	2-4	2-3	3	2-9	250 to 550	130°C	4	1-3	1-2	2	4	1-3
Silicone Varnish		1000-1500	4.0 to 20.0	2-5	2-4	3-4	2-9	250 to 400	180°C	2	1-2	8-10	2	3-4	4-10
Laminates	Considering most appropriate type for rating. (See Detailed or Laminates Charts)			1	1		1	1	105-180°C		1	1	1	2	2

APPLICATION CHART 12: FIELD POLE PROTECTION FOR MACHINES AND GROUND INSULATION FOR TRANSFORMERS

Rating of 1 — best characteristic; rating of 10 — poorest characteristic but still usable

Material	General Remarks	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Creasing (resistance to)	Tear (resistance to)	Tensile (Breaking) Strength, lb/in. width	Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to: Moisture	Oil	Acid	Base	Solvent
Paper	Kraft	160	5.0	9	4	5	4	MD 250 CMD 260	105°C	7	5	8	4	9	9	4
Pressboard	Acetate coated		90.0													
Uncut Mica	Block mica	1500		4	9	10			180°C	1	5	2	2	2	3	1
Mica Paper Backed Conventional Varnish			90.0	8	5	7	8		105°C	4	8	8	5	9		8
Glass Backed 1) Silicone Varnish	Basis for rating— .002 glass .004 mica	600 (at 180°C)		5	4	9	3		180°C	2	9	2	10	5		9
2) Conventional Varnish		900	90.0	5	4	9	3		130°C	2	7	2	2	3	3	4

11. *Nonrotating Equipment*

Design Considerations in Transformers.—As for motors and generators, the application governs the insulation design of the transformers. The principal types are the distribution and power supply transformers, each having its own operating characteristics. The latter type can be subdivided into resistance welding transformers and those which are similar in function to the distribution transformers but on a smaller scale.

The factors which affect the transformer insulation are:

1. External conditions—moisture, chemicals, dust, ambient temperature.

2. Load cycle—length of operating period, frequency of operating cycle, starting and stopping, overloads, degree, frequency, and switching surges.

The effect of moisture and chemicals is apparent. Since dust is more important than is normally considered, it deserves further consideration. For dry-type transformers the dust accumulation on the windings affects the rate of thermo-conductivity of the insulation. Where the rate of dust accumulation is excessive, the transformer must be cleaned periodically.

The second group presents a greater problem to the designer, as it involves the economical and efficient use of the transformer. A thorough knowledge of the application to which the unit will be put is required. In most cases not all the factors enter into the design of any type of transformer.

In applications where overloads are not expected, the length of the operating period should be considered. If at normal load that period is short enough so that the unit will not reach its rated hot-spot temperature by a considerable amount, the size of the transformer may be reduced so far as to permit it to radiate the amount of heat created. This can be done only if the frequency of the operating cycle is such that the interval between operations is long enough for the transformer to cool down to a prescribed value.

Where the idle periods are longer than their operational periods, the transformer may absorb moisture. The effect of moisture on the insulation has been previously discussed.

If there is a continual starting and stopping in a relatively short period of time, the initial magnetic stresses will increase the amount of wear and abrasion on the insulation.

If the degree and frequency of overloads are known, the design of the transformer may be judged accordingly. The 10 deg C rule for

APPLICATION CHART 12: FIELD POLE PROTECTION FOR MACHINES AND GROUND INSULATION FOR TRANSFORMERS

Rating of 1 — best characteristic; rating of 10 — poorest characteristic but still usable

Material	General Remarks	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Creasing (resistance to)	Tear (resistance to)	Tensile (Breaking) Strength, lb/in. width	Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to				
												Moisture	Oil	Acid	Base	Solvent
Paper	Kraft	160	5.0	9	4	5	4	MD 250 CMD 260	105°C	7	5	8	4	9	9	4
Pressboard	Acetate coated		90.0													
Uncut Mica	Block mica	1500		4	9	10			180°C	1	5	2	2	2	3	1
Mica Paper Backed Conventional Varnish			90.0	8	5	7	8		105°C	4	8	8	5	9		8
Glass Backed 1) Silicone Varnish	Basis for rating— .002 glass .004 mica	600 (at 180°C)		5	4	9	3		180°C	2	9	2	10	5		9
2) Conventional Varnish		900	90.0	5	4	9	3		130°C	2	7	2	2	3	3	4

11. *Nonrotating Equipment*

Design Considerations in Transformers.—As for motors and generators, the application governs the insulation design of the transformers. The principal types are the distribution and power supply transformers, each having its own operating characteristics. The latter type can be subdivided into resistance welding transformers and those which are similar in function to the distribution transformers but on a smaller scale.

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1. External conditions—moisture, chemicals, dust, ambient temperature.

2. Load cycle—length of operating period, frequency of operating cycle, starting and stopping, overloads, degree, frequency, and switching surges.

The effect of moisture and chemicals is apparent. Since dust is more important than is normally considered, it deserves further consideration. For dry-type transformers the dust accumulation on the windings affects the rate of thermo-conductivity of the insulation. Where the rate of dust accumulation is excessive, the transformer must be cleaned periodically.

The second group presents a greater problem to the designer, as it involves the economical and efficient use of the transformer. A thorough knowledge of the application to which the unit will be put is required. In most cases not all the factors enter into the design of any type of transformer.

In applications where overloads are not expected, the length of the operating period should be considered. If at normal load that period is short enough so that the unit will not reach its rated hot-spot temperature by a considerable amount, the size of the transformer may be reduced so far as to permit it to radiate the amount of heat created. This can be done only if the frequency of the operating cycle is such that the interval between operations is long enough for the transformer to cool down to a prescribed value.

Where the idle periods are longer than their operational periods, the transformer may absorb moisture. The effect of moisture on the insulation has been previously discussed.

If there is a continual starting and stopping in a relatively short period of time, the initial magnetic stresses will increase the amount of wear and abrasion on the insulation.

If the degree and frequency of overloads are known, the design of the transformer may be judged accordingly. The 10 deg C rule for life will be the criterion as to whether a higher class rating of insulation should be used. If the overloads per unit of time are so few that the life of the insulation is not decreased substantially, the insulation designed for its normal load will be satisfactory. Oil-filled transformers are limited by the temperature resistance of the oil used as the dielectric. Distribution transformers are designed for a 50-percent overload for a short time, to take care of peak loads. Where the peak conductors or frequency of overloads is excessive a higher grade of insulation must be used.

Those factors which affect the design indirectly have been discussed—reliability, life, and weight.

The forces created by the magnetic fields cause movement of the conductors. The strength of these forces determines the amount of wear and abrasion on the insulation. Short circuits result in very strong forces which might cause undue damage to the insulation. Resistance welding transformers operate under short-circuit conditions, so that they have to be designed mechanically strong and with a high rate of thermo-conductivity.

As a result of World War II, the use of three-phase transformers has increased to such an extent that today two-thirds of the new power transformers purchased are three-phase (compared with 10-15 percent 10 yr ago). New materials and insulating methods have greatly reduced the size of these transformers and thus made handling and installation easier. The space requirements, foundations, and installation costs are less than for three single-phase units. These advances have largely eliminated the previous causes of transformer failure and brought three-phase transformers into wide use.

The following items must be considered in the design of transformers:

1. Highest possible operating temperature
2. Protection of insulation against moisture
3. Power factor in the high voltage range
4. Dielectric strength of the insulating material
5. Unexpected overload during peak loads
6. Lighting surges
7. Rate of thermo-conductivity of the insulation — the higher the better
8. Mechanical strength of the insulation
9. Impedance kept within prescribed limits.

For each type of transformer some of these items need not be considered. Thus, the consideration of the electrical characteristics of the insulating material is of minor importance in resistance welding transformers, since the usual voltages are 220 volts and less, and present few if any serious difficulties.

In one group of transformers that were built, a Class A insulation was used between the core and the group of coils, and only at these two extreme ends. The other insulation was Class B, which covers about 99 percent of the total. The transformer was nevertheless classified as Class A. The transfer of heat through it was not fast enough, and its deterioration resulted. Very often whenever two classes of insulation are used in conjunction on a piece of equipment, the equipment will be rated under the class which has the lowest rating of the two.

It has been stressed previously that it is the service requirements which determine the selection of an insulating material for a piece of apparatus. The service requirements for a transformer-insulating material are:

1. To withstand the voltage (steady-state) to ground from all parts of the winding. (For a three-phase unit it is 57.7 percent of line-to-line terminal voltage.)
2. To withstand line faults — e.g., if one line of delta-connected transformer is grounded, resulting in full line voltage to ground. For a wye-connection various voltages can result, depending on the fault.
3. To withstand overvoltages from switching surges and arcing grounds. These can be 2½–6 times the normal voltage to neutral. So long as the proper lighting protection is utilized, the transformer will withstand these surges, since the voltage distribution throughout the windings is approximately uniform. The switching and impulse surges strength of its insulation to ground are almost equal to one another.
4. To withstand impulse or lighting surges.

Designers must take into consideration other factors as well. While there is inherent within the transformer a certain amount of overload capacity, complete utilization of this capacity requires that parts of the transformer (tap changes, bushings, leads, etc.) be designed with this in mind. One more point is that the conductor insulation will be at the greatest temperature. The other insulation, which is not in thermal contact with the copper, will be at an appreciably lower temperature and will have the greatest voltage stresses applied to it. Since the conductors will not be subjected to line-to-line or line-to-ground voltages, probability of failure from overheat and electrical breakdown is greatly reduced.

A designer of a piece of equipment must take into account all factors that have anything to do with the choice of insulation. All factors are of equal importance, since all affect the over-all performance. Each material that goes into making up the insulation combination was chosen because in one way or another it satisfied the above factors. A material by itself might have an excellent property, but when used in combination this property cannot always be utilized to its fullest extent. No one thing does the *prime* job; it is the combination that does the work, regardless of mechanical or electrical performance.

(a) Liquid In Chapter III, oil was discussed in detail as a liquid dielective for transformers. Parts of this material are repeated in this chapter, for emphasis. The advantages of oil are that it serves as a good cooling and insulating medium and has good self-healing qualities. Its disadvantages are flammability, slugging, and formation of acids.

The insulation largely determines the continuous and overload ratings of any piece of electrical apparatus. There are two factors for oil-filled transformers which permit a high overload for short periods of time—the very large heat capacity of the oil, and the high rate of heat transfer from the metal parts to the oil. The solid insulation, too, must be protected from excessive temperatures under overload conditions. At these temperatures the insulation can lose a large fraction of its strength quickly.

The insulation temperature is the same as the oil temperature, rather than at the copper temperature. Only the insulation touching the copper itself reaches the temperature of the copper. The effect of a loss in tensile strength on the surface of the insulation facing the copper is not serious, and the insulation is in place in the transformer. A loss in tensile strength does not result in an equal loss of compressive strength.

Insulating materials in oil will withstand higher temperatures in the absence of air than in its presence.

(b) Dry-Type As the name signifies, dry-type transformers are freed of all liquids, and their cores, coils, and other parts are cooled by the forced or natural circulation of air. Since the major insulation is air and porcelain, the transformer is essentially explosion- and fire-proof. Mostly inorganic insulation is used, such as glass, mica, asbestos, porcelain, and combinations of these or other materials which are bonded together with a good heat-resisting varnish.

Between the high and low-voltage windings, air ducts are formed by spacers of mica, glass, porcelain, or asbestos. Dirt which comes into the duct falls to the bottom of the transformer, thus eliminating horizontal creepage surfaces in the high-voltage coils.

A good varnish and curing cycle will impart to the insulation surface a smooth, tough, glossy finish which gives it a high resistance to dirt, moisture, and heat.

In oil-filled transformers, arcing causes decomposition of the insulation and the liquid. The liquid helps spread the decomposition action, due to the arcing and to the acid present in it. In the dry-

type transformers no liquids are present to cause the failure to spread. Corrosive atmospheres have little effect on the latter type. Their full-load efficiency and impedance are about the same as those of the oil-filled transformers. The ratings of the dry-type may be increased from one-quarter to one-half by the use of forced air-cooling. Class B insulated dry-type transformers have operated continuously for a period of more than 24 hr with an overload ranging from 150 to 200 percent of full load, without any noticeable effect on the insulation.

The advantages of the dry-type can be listed as follows:

1. Less maintenance required than for oil-filled type
2. Easier to handle — lighter in weight and smaller in size for the same rated oil-type transformer
3. Explosion- and fire-proof
4. Lower insurance rates
5. Elimination of sludge trouble
6. Elimination of acids due to decomposition of oil

The subject of dry-type transformers is summed up thus by W. W. Satterlee of Westinghouse:

> "Many large transformers of the dry-type design have been in continuous operation for more than seven years. Today there are over 2000 transformers in service totaling approximately 1,000,000 KVA. Never has a breakdown of the winding insulation occurred in any of these transformers which could be directly attributed to an excessive winding temperature, and accumulation of dirt, the effects of condensation, or operation in a humid or any other atmosphere."*

Materials Used.—For oil-filled transformers the insulation material must be resistant to deterioration by oil, and the varnishes should not be soluble in oil.

The conductor should have heat-resistant qualities and also be thin and flexible in order that it may withstand bending, compressive and abrasive stresses incurred during the winding operation. (See Application Charts 1 and 2.)

Coil wrappers should be moisture-, chemical-, and thermal-resistant. (See Application Chart 3.)

Coil binding tape should have mechanical strength in order that it may perform its function of binding the coil. (See Application Chart 4.)

Layer insulation should have mechanical and moderate dielectric strength as well as thermal endurance. (See Application Chart 5.)

Primary to secondary insulation must have the usual mechanical and electrical strength. In dry-type transformers the mechanical strength may be provided by the structural parts. (See Application Chart 12.)

* "Some Developments in Modern Transformer Design," *Iron and Steel Engineer*, June, 1945.

Ground insulation consists of the barriers and core binding tape, which must be mechanically strong to withstand the burr penetration and the cutting action of the core. (See Application Chart 12.)

Lead wire (which includes sleeving and tubing) must be flexible, resistant to chemicals, and have high visulation resistance. What has been said under the heading "lead wire" under Rotating Machines also applies here. (See Application Charts 8 and 9 and Appendix B, Table 6.)

Structural insulating parts must have good dielectric strength, be heat resistant, and be strong. In humid atmospheres these parts must have good arc resistance to prevent flashing and creeping. (See Application Chart 12.)

V. Trends in Insulation

During the search for information and the attempt to make the charts it became apparent that the present classification of electrical equipment solely in terms of hot-spot temperatures is inadequate. A suggestion for the basis of a new rating system would be the idea of standard or ordinary and premium or exceptional equipment.

Under the standard classification would come the majority of equipment used for general over-all purposes—i.e., a piece of equipment that does not have to have a special design feature or that would not operate under adverse conditions. In this group a minimum number of general requirements would be established, to facilitate and clarify the old setup. Another reason is that regardless of which company the piece of standard apparatus is purchased from, it will have essentially the same characteristics.

The premium group could include the different types of equipment which must be designed to operate under special conditions. For example, the group might be tentatively classified thus:

Premium V: For exceptional mechanical strength
Premium W: For exceptional moisture resistance
Premium X: For exceptional chemical resistance
Premium Y: For exceptionally high-speed operation
Premium Z: For exceptionally high-temperature operation

Engineers in the field have stated that some insulation failures of equipment have been due to unpredictable emergency conditions. Thus the added safety factor of a premium apparatus would act as insurance against such conditions. With this broad classification, it would be possible to order a Premium "WZ" machine—one that should be expected to have unusually high moisture resistance and also a high operating temperature.

Under the present classification the user has the choice of several temperature ratings and several methods of enclosure. It would appear that such a classification is inadequate to cope with the variety of operating conditions met in present practice.

A current practice that encourages adoption of this suggestion is the use of Class A materials in addition to organic binders for Class B units. The definition of a Class B machine leaves a loophole, since it states that a non-impairing amount of Class A materials may be used for structural purposes. The purpose of any combination is to obtain some special design feature in the equipment. This means that it must be borne in mind, with limitations, that the complete abolishment of temperature rating is not advocated but rather that it be a subordinate requirement under the two main divisions of standard and premium.

Another item revealed by the investigation into electrical insulation is the need of eliminating many of the countless varnishes now on the market. Many engineers expressed the hope that the number of varnishes could be reduced to a reasonable number that would fall into general groups distinct from one another. The attainment of this aim would, as was pointed out in Chapter I, greatly facilitate setting up the charts.

For the reasons given in Chapter IV there is a tendency toward use of an ever increasing number of high-temperature and high-speed machines that possess certain inherent advantages. The advent of new materials has made and will continue to make their use advisable in many applications.

A growing idea in industry is that no matter what type of insulation is used in a machine, except for uncut mica and plastics, it cannot be relied on to have a dielectric strength greater than an equal thickness of air, because a continuous film of varnish cannot be imparted to the base material so that no pinholes exist. The existence of these pinholes will cause the value of dielectric strength for one type of insulation to vary anywhere from the value it would have for an equal thickness of air up to a maximum value for a perfect film of varnish over the base material.

PEDIGREE-CHARACTERISTIC ANALYSIS CHART

Number	Description	Special Qualities	Principal Components	Solids Content	Baking Time	Baking Temperature	Air-Drying Time	Life	Specific Gravity	Baumé	Solvent
111	Clear Oil-Proof Baking Varnish	Extreme flexibility; deep penetration; oil and waterproof; highly resistant to acids and alkalies	Flexible, durable, and prepared oils	50%	12 to 15 hr	250°F 120°C	X	Excellent	.850	35°	V.M. & P. Naphtha
112	Clear Coil Baking Varnish	Good flexibility; oil and waterproof; highly resistant to acids and alkalies	Synthetic resins and vegetable oils	48%	10 to 12 hr	250°F 120°C	X	Very good	.871	31°	V.M. & P. Naphtha
113	Clear Tough Phenolic Baking Varnish	Oil and waterproof; produces tough, hard, practically infusible protection for high speed units; excellent bonding	Phenolic resin and special oils	50%	8 to 12 hr	135°F 275°C	X	Good	.935	17°	Solvesso #2 or equivalent
115	Clear Hard Synthetic Baking Varnish	Tough, hard finish; good bonding qualities; oil and waterproof	Synthetic resin and vegetable oils	50%	6 to 8 hr	275°F 235°C	X	Good	.734	29°	V.M. & P. Naphtha
116	Clear Formvar Baking Varnish	Designed for Formvar, Formex, or Hyflex wire units and only that type of magnet wire; oil and waterproof	Phenolic resin and treated drying oils	50%	6 hr	275°F 135°C	X	Good	.916	23°	Xylol
117	Clear Phenolic Baking Varnish	Good penetration; deep drying; excellent bonding qualities; produces tough, hard, varnish film; oil and waterproof	Phenolic resin and treated drying oils	50%	6 to 8 hr	275-300°F 135-150°C	X	Fair	.928	21°	Solvesso #2, V.M. & P. Naphtha, or equivalent
118	Clear Automative Varnish	Excellent penetration; tough hard finish; intended for automotive or similar armatures; waterproof and oil resistant	Synthetic resins and gums and prepared oils	50%	4 to 6 hr	250°F 120°C	X	Good	.865	32°	V.M. & P. Naphtha
119	Clear Quick Baking Varnish	Possesses same general characteristics as Nos. 111 and 112 except bakes out faster and costs less	Prepared gums and oil. Vegetable oil	50%	5 to 6 hr	250°F 120°C	X	Fair	.855	35°	V.M. & P. Naphtha
1110	Clear Hard Phenolic Baking Varnish	Similar to No. 113 except is more viscous and produces very hardest finish and heaviest building up. Highly recommended for high-speed units	Phenolic resin and special oils	57%	8 to 12 hr	275-300°F 135-150°C	X	Good	.979	13°	Sylol or Solvesso #2 or equivalent

PEDIGREE-CHARACTERISTIC ANALYSIS CHART (CONTINUED)

Number	Description	Special Qualities	Principal Components	Solids Content	Baking Time	Baking Temperature	Air-Drying Time	Life	Specific Gravity	Baumé	Solvent
1111	Amber Heavy Synthetic Baking Varnish	Similar to No. 113 except is deeper amber and has heavier build-up	Phenolic resin and special oils	46%	8 to 12 hr	275-300°F 135-150°C	X	Excellent	.959	16°	Sylol or Solvesso #2 or equivalent
211	Black Oil Proof Baking Varnish	Extreme flexibility; oil and waterproof; highly recommended to acids and alkalies; deep penetration; used for similar applications as No. 111	Waterproof gums and prepared oils	47%	10 to 12 hr	250°F 120°C	X	Excellent	.865	32°	V.M. & P. Naphtha
212	Black Plastic Baking Varnish	Good flexibility and elasticity; good build-up; excellent impregnation; moderately oil and waterproof; highly resistant to acids	Gilsonite and linseed oil	50%	10 hr	250°F 120°C	X	Fair	.882	29°	V.M. & P. Naphtha
213	Black Synthetic Baking Varnish	Good penetrating and deep drying qualities; excellent bonding properties; oil and waterproof	Partial synthetic resins and treated drying oils	55%	6 to 8 hr	265°F 110°C	X	Very good	.882	29°	V.M. & P. Naphtha
215	Black Quick Baking Varnish	Good build-up; highly resistant to oils, water, and chemicals; dries smooth and glossy	Gilsonite and synthetic resins and prepared oils	50%	3 to 6 hr	240°F 116°C	X	Fair	.860	33°	V.M. & P. Naphtha
	Clear Baking or Long Air-Drying Varnish	Excellent penetrating and binding qualities; oil, water, and chemical resistant; baking recommended but will air-dry	Synthetic resin and vegetable oils	45%	3 to 6 hr	240°F 116°C	8 to 12 hr	Good	.865	32°	V.M. & P. Naphtha
	Clear Synthetic Air-Drying Impregnating Varnish	Provides tough oil and waterproof finish and good build-up	Phenolic and synthetic resins and suitable drying oils	50%	30 min	250°F 120°C	2 hr	Fair	.953	17°	Toluol or Solvesso #1 or equivalent
	Black Air-Drying or Baking Varnish	Good penetrating qualities; waterproof; resistant to acids but not oils; recommended for field coils and general purpose work; air dries or bakes out quickly	Gilsonite and suitable drying oils	49%	1 to 2 hr	220-240°F 105-115°C	3 to 4 hr	Fair	.965	32°	V.M. & P. Naphtha
131-C	Clear Spirit Varnish	Oil and waterproof; resistant to acids and alkalies; recommended as a surface finishing coat over baked coils or for maintenance purposes	Natural resins and plasticizer	47%	X	X	30 min	X	.887	28°	Denatured Alcohol

PEDIGREE-CHARACTERISTIC ANALYSIS CHART (CONTINUED)

Number	Description	Special Qualities	Principal Components	Solids Content	Baking Time	Baking Temperature	Air-Drying Time	Life	Specific Gravity	Baumé	Solvent
134	Orange Spirit Varnish	Good resistants to oils, water, acids, and alkalies; recommended as an orange shellac replacement or as a finishing varnish for applications similar to those of Nos. 131, 231, and 237	Natural resins and plasticizer	48%	X	X	30 min	X	.940	19°	Denatured Alcohol
135-D	Clear Finishing Filling Varnish	Used as a finishing coating and as a filler between core laminations on power transformers	Natural resins and suitable drying oils	36%	X	X	1 to 2 hr	X	.904	24°	Denatured Alcohol
231	Oil Proof Spirit Finishing Varnish	Performs the same functions as No. 131-C; provides black glossy finishing coat over baked coils; can be used for general maintenance purposes	Synthetic resins and prepared oils	46%	X	X	30 to 60 min	X	.916	23°	Denatured Alcohol
233	Black Finishing Varnish	Provides good build-up with glossy black coating; waterproof; highly resistant to alkalies	Gilsonite and treated oils	42%	X	X	60 min	X	.855	24°	V.M. & P. Naphtha
234	Black Oil-Proof Finishing Varnish	Air-dries or bakes out to a flexible heavy finishing coat; oil and waterproof	Synthetic resins and special oils	54%	2 hr	250°F 120°C	6 hr	Good	.882	29°	Mineral Spirits
235	Black Heavy Spirit Varnish	Provides heavy tough finishing coat; similar to No. 231 except provides greater build-up	Natural gums and plasticizer	56%	X	X	1 hr	X	1.014	X	Denatured Alcohol
237	Black Spirit Varnish	Same as No. 231 except provides slightly less build-up and is lower in price	Special gums and plasticizer	45%	X	X	30 min	X	.947	18°	Denatured Alcohol
238	Black Finishing and Filling Varnish	Waterproof and resistant to acids and alkalies; not oilproof and quick drying	Highest grade refined black gums	32%	X	X	1 to 2 hr	X	.865	32°	V.M. & P. Naphtha
239	Black Surfacing Lacquer	Used as a protective sealer for small coils; provides extremely tough, impervious film	X	X	X	X	10 min	X	.979	13°	Lacquer Thinner

Pedigree-Characteristic Analysis Chart (Continued)

Number	Description	Special Qualities	Principal Components	Solids Content	Baking Time	Baking Temperature	Air-Drying Time	Life	Specific Gravity	Baumé	Solvent
132	Clear Air Drying Coreplate Varnish	Excellent adhesive qualities and will not flake off when punched	Synthetic resins and drying oils	34%	X	X	30 min	X	.887	28°	V.M. & P. Naphtha
133	Clear Flashing Coreplate Varnish	Highest quality clear but is recommended for use only in specially designed ovens and under controlled conditions	X	13%	Flash drying time—3 to 5 min			X	.887	28°	V.M. & P. Naphtha
232	Black Air-Drying Coreplate Varnish	Excellent adhesive qualities and will not flake off when punched	Gilsonite and treated oils	17%	X	X	15 min	X	.806	44°	V.M. & P. Naphtha
236	Black Flashing Coreplate Varnish	Highest quality black but is recommended for use only in specially designed ovens and under controlled conditions	X	48%	Flash drying time—3 to 5 min			X	.876	30°	V.M. & P. Naphtha
141	Clear Protective Sealer	Protects underlying insulated windings from attack by oil, grease, gas, acids, alkalies, water; also provides smooth, tough outside coating very resistant to mechanical and chemical abuse. Similar to Nos. 241 and 341	Synthetic resins and oils	45%	2 to 3 hr	260°F 125°C	4 to 6 hr	Good	.993	11°	Xylol or Solvesso #2 or equivalent
143	Clear Synthetic Insulator	Used for same applications as No. 141, but has a specially high resistance to alkalies	Phenolic and synthetic resins and oils	53%	2 to 3 hr	260°F 125°C	4 to 6 hr	Good	.940	19°	Xylol or Solvesso #2 or equivalent
241	Black Protective Sealer	Similar to characteristics and uses of Nos. 141 and 341 except for colors	Synthetic resins and oils	48%	2 hr	250°F 120°C	4 to 6 hr	Good	.996	15°	Xylol or Solvesso #2 or equivalent
243	Black Synthetic Insulator	Used for same application as No. 241 but has a specially high resistance to alkalies	Synthetic resins and oils	49%	2 to 3 hr	260°F 125°C	4 to 6 hr	Good	.893	27°	Yoluol, Xylol or corresponding Solvesso
341	Red Protective Sealer	Similar in characteristics and uses to Nos. 141 and 241 except for its glossy red hue	Synthetic resins and oils	63%	2 hr	250°F 120°C	4 to 6 hr	Good	1.228	X	Xylol

Pedigree-Characteristic Analysis Chart (Concluded)

Number	Description	Special Qualities	Principal Components	Solids Content	Baking Time	Baking Temperature	Air-Drying Time	Life	Specific Gravity	Baumé	Solvent
342	Red Oil-Proof Enamel	Recommended for oilproofing electrical equipment, especially on ends of commutators	Natural gums and drying oils	52%	X	X	30 min	Good	1.2183	X	Denatured Alcohol
343	Red Synthetic Insulator	Similar to Nos. 143 and 243 except color; renders best possible protection against caustics and alkalies	Phenolic resins and vegetable drying oil	59%	2 to 3 hr	250°F 120°C	4 to 6 hr	Good	1.1789	X	Toluol
151	Clear Coil Sticking Varnish	Used to cement tape ends, cloth, mica, etc.; oilproof and slow setting	Natural gums and plasticizer	57%	X	X	45 min	X	.940	19°	Denatured Alcohol
154	Clear Quick Sticking Varnish	Recommended for all sticking purposes; fastest adhesive qualities; oil, water resistant	Synthetic gums and plasticizer	55%	May also be taken		10 min	X	.993	11°	Solvesso #1
261	Black Machinery Enamel	Produces glossy and durable oilproof finish; best quality black and excellent adhesion	Special synthetic base	X	X	X	45 to 60 min	X	.871	31°	For brushing turpentine; for spraying Toluol or Xylol
262	Black Air-Drying Insulating Paint	Provides protection for meter panels and cables, etc.	Gilsonite base	X	X	X	1 hr	X	.850	35°	V.M. & P. Naphtha
461	Gray Machinery Enamel	Similar to No. 261 except Standard Dark Machinery Gray color	Oil extended alkyd resin	X	X	X	45 to 60 min	X	1.1471	X	For brushing turpentine; for spraying Toluol or Xylol
171	Clear Oil-Proof Impregnating Compound	Maximum oil resisting qualities; high dielectric strength	Special oil resisting compounds	100%	X	X	X	X	Solid		Supplied at melting point of 100°C, 212°F
271	Black Pocket Sealing Compound	Oil resistant; adheres well to porcelain, iron, and cable	Special oil resisting compounds	100%	X	X	X	X	Solid		Supplied at melting point of 100°C, 212°F

Appendix A:

An AIEE Standard Classification of Insulating Materials

Class	*Description of Material*
O . . .	Consists of cotton, silk, paper, and similar organic materials when neither impregnated[1] nor immersed in a liquid dielectric.
A	Consists of: 1) cotton, silk, paper, and similar organic materials when either impregnated[1] or immersed in a liquid dielectric; 2) molded and laminated materials with cellulose filler, phenolic resins and other resins of similar properties; 3) films and sheets of cellulose acetate and other cellulose derivatives of similar properties; and 4) varnishes (enamel) as applied to conductors.
B	Consists of mica, asbestos, fiber glass, and similar inorganic materials in built-up form with organic binding substances. A small proportion of Class A materials may be used for structural purposes only[2].
C	Consists entirely of mica, porcelain, glass, quartz, and similar inorganic materials.

[1] An insulation is considered to be "impregnated" when a suitable substance replaces the air between its fibers, even if this substance does not completely fill the spaces between the insulated conductors. In order to be considered suitable, the impregnating substance must have good insulating properties; must entirely cover the fibers and render them adherent to each other and to the conductor; must not produce interstices within itself as a consequence of evaporation of the solvent or through any other cause; must not flow during the operation of the machine at full working load or at the temperature limit specified; and must not unduly deteriorate under prolonged action of heat.

[2] The electrical and mechanical properties of the insulated winding must not be impaired by application of the temperature permitted for Class B material. (The word "impair" is here used in the sense of causing any change which could disqualify the insulating material for continuous service.) The temperature endurance of different Class B insulation assemblies varies over a considerable range, in accordance with the percentage of Class A materials employed and with the degree of dependence placed on the organic binder for maintaining the structural integrity of the insulation.

For purposes of standardization, "hottest-spot" temperatures have been established for each class of materials as follows:

For Class O Material.................................... 90 deg C (194 deg F)
For Class A material....................................105 deg C (221 deg F)
For Class B material....................................130 deg C (266 deg F)
For Class C material.................................... No limit selected

In response to the development of high-temperature insulating materials, the AIEE recently set the standards for Class H insulation. The hot-spot rating for this new Class is 180 deg C (356 deg F).

Appendix B

Table 1

Summary of Information on Materials Used for Insulating Various Parts of Machines

Part	Class A	Class B	Class H	Remarks
Strand (field and armature)	Enamel; varnished cotton, rayon, silk, or nylon	Asbestos in various forms. Mica backed tapes. Glass fiber	Asbestos or glass fiber impregnated with silicone	Must be thin, flexible, must have heat resistant properties
Conductor	Cotton tape or yarn. Varnished cotton, rayon, or silk tape	Asbestos tape. Mica backed with glass fiber and bonded with conventional varnish. Glass tape	Mica, sheet. Silicone-glass tape. Mica backed with glass fiber or asbestos and bonded with silicone	Must withstand the bending, compressive, and abrasive stresses incurred during winding operations
Coil (field and armature) a) Tapes	Varnished cotton. Woven cotton, rayon, or silk tapes. Paper	Mica backed with glass fiber and bonded with conventional varnish. Asbestos tape. Glass tape	Asbestos or glass fiber impregnated with silicone	Tape provides mechanical strength and moisture resistance. Must resist pounding, creasing and bending
b) Wrapper	Mica backed with paper or cotton and bonded with conventional varnish. Varnished cotton, rayon or silk	Mica backed with glass fiber and bonded with conventional varish. Mica. Varnished glass cloth	Mica backed with glass fiber or asbestos and bonded with silicone	Wrapper provides moisture resistance. Dielectric strength
Phase	Mica backed with paper or cotton and bonded with conventional varnish. Varnished cotton, rayon, or silk	Mica backed with glass fiber and bonded with conventional varish. Varnished glass cloth	Mica backed with glass fiber or asbestos and bonded with silicone. Asbestos or glass fiber impregnated with silicone	High dielectric strength. Moisture and chemical resistance. Mechanical strength
Layer (field and armature)	Mica backed with paper or cotton and bonded with conventional varnish. Pressboard. Fish or rag paper	Oiled asbestos paper. Molding mica. Asbestos or glass laminate. Mica backed with glass fiber and bonded with conventional varnish	Mica sheet. Mica backed with glass fiber or asbestos and bonded with silicone. Asbestos or glass fiber impregnated with silicone	Dielectric strength, since it may be insulating between phases
Slot liners Troughs	Paper alone or composite paper. Varnished cotton, rayon, or silk	Mica sheet. Combinations of glass and asbestos. Varnished glass cloth. Mica backed with glass fiber and bonded with conventional varnish	Mica backed with glass fiber or asbestos and bonded with silicone. Glass fiber impregnated with silicone	Must be mechanically strong to withstand abrasion and cutting due to burrs. Provides ground insulation between coils and the sides of the slot. Provides protection during winding for the coils

Table 1 (Concluded)

Summary of Information on Materials Used for Insulating Various Parts of Machines

Part	Class A	Class B	Class H	Remarks
Slot Wedges	Treated hard maple. Treated fiber or canvas base laminate	Asbestos or glass base laminate (phenolic or melamine)	Glass or asbestos base silicone or melamine, laminates	Mechanical strength to hold coils in position. Excessive temperatures will cause Class A materials to split and crack and work out of the slot
End Laminations	Paper or cotton cloth laminated phenolic	Asbestos or glass base laminate (phenolic or melamine)	Glass or asbestos base silicone or melamine, laminates	Mechanical protection at the ends of the armature for the coils. Must be strong and heat resistant
Lead and Intercoil and Sleeving	Cotton tape. Braided cotton sleeving. Plastic tubing. Cotton or rayon covered lead wire	Varnished glass tubing. Mica and treated glass tapes. Asbestos or glass tape. Braided asbestos or glass sleeving. Glass or asbestos braided lead wire	Silicone glass tubing. Mica tapes backed with glass fiber bonded with silicone	Materials act as a spacer and provide mechanical protection rather than dielectric strength
Commutator	Mica	Mica	Mica	The insulation must be temperature resistant (mechanically and electrically), moisture resistant. Mechanical separation which must be stable under heat and moisture conditions. If the mica is the hard type it must be undercut
Field Pole Protection	Pressboard or paper	Mica. Mica backed with glass fiber and bonded with a conventional varnish	Mica. Mica backed with glass fiber or asbestos and bonded with silicone	Provides ground insulation and mechanical protection
Banding Wire Insulation a) Core	Fish or rag paper. Rag pressboard	Uncut mica or varnished asbestos paper or glass cloth	Glass or asbestos cloth	Mechanical strength to provide a resilient protecting covering
b) Coil	Treated duck, fish paper, rag paper, and fullerboard	Flexible mica, oiled asbestos paper, or varnished asbestos or glass cloth	Asbestos or glass fiber impregnated with silicone	Mechanical strength of primary importance

TABLE 2
SUMMARY OF INFORMATION ON MATERIALS USED FOR INSULATING VARIOUS PARTS OF TRANSFORMERS

Component Parts	Class A (oil-filled)	Class B (dry-type)	General Remarks	
			Oil-Type	Dry-Type
Strand	Kraft paper. Treated cloth	Asbestos. Glass	Should be thin and flexible. Should have heat-resistant qualities and withstand bending. Compressive and abrasive stress incurred during winding operations	
Layer	Kraft paper. Untreated cloth. Pressboard	Asbestos (L.V.). Varnished glass cloth (L.V.). Mica (H.V.). Porcelain	Must have mechanical and moderate dielectric strength as well as thermal endurance	Must have mechanical and moderate dielectric strength
Coil	Treated paper	Air. Mica. Varnished glass cloth. Varnished asbestos cloth. Mica backed with glass or asbestos bonded with conventional varnish or silicone	Varnish must not be soluble in oil. Chemical resistance	Moisture, chemical, and thermal resistant
Primary to Secondary	Laminated phenolic barriers. Pressboard. Bakelite tubes	Mica backed with glass and bonded with conventional varnish or silicone. Air ducts. Varnished glass cloth	Must have dielectric and mechanical strength	Must have dielectric and mechanical strength. If air is used, the mechanical strength is provided by structural parts
Coil Binding Tape	Untreated cloth tape	Glass tape	Must have mechanical strength. Binds coils and shields the coil insulation from burrs on the core	
Lead Wire Sleeving and Tubing	Untreated cloth. Treated cloth	Glass. Varnished glass	Must be flexible	Must be flexible and resistant to chemicals
Structural Insulating Parts a) Coil Supports	Pressboard. Synthetic-resin products. Oil. Laminated phenolic barriers	Porcelain. Glass. Mica. Asbestos. Air ducts. Varnished glass cloth. Mica backed with glass fiber and bonded with conventional varnish or silicone	Must have good dielectric strength and be heat-resistant. Must be strong	Must have good dielectric and mechanical strength
b) Barriers	Bakelite Tubes			
Ground	Pressboard. Varnished muslin	Mica backed with glass fiber and bonded with conventional varnish or silicone	The ground insulation consists of the barriers and core binding tape	

TABLE 3 — PART I*
SYNTHETIC INSULATING MATERIALS USED FOR STRUCTURAL PURPOSES

Material	Electrical Properties	Mechanical Properties	Solvent Properties
Phenolic Resins Cast	Poor high energy arc resistance	Method of forming restricts cast phenolic to small pieces at present	Excellent resistance to most organic solvents. Softened by acetone
Molded (with filler)	Arc resistance and dielectric strength vary widely with filler	Lower tensile strength than laminated phenolics	Excellent resistance to organic solvents
Laminated	Arc resistance and dielectric strength vary widely with filler	Determined by filler	Excellent resistance to most organic solvents. Blistered by acetone
Urea Formaldehyde Molded	Fair arc resistance		Unaffected by most organic solvents
Melamine Formaldehyde Laminated Glass Filler	Excellent arc resistance. Dielectric strength 490 vpm after 96 hr at 25°C-70% RH		
Aniline Formaldehyde Unfilled Sheet	Dielectric strength 720 vpm (short time) 150° low power factor. Dielectric constant (10 cycles) = 3.62	Available in flexible sheets or rods	Excellent resistance to organic solvents

TABLE 3 — PART II*
SYNTHETIC INSULATING MATERIALS USED FOR STRUCTURAL PURPOSES

Material	Acid Resistance	Alkali Resistance	Thermal Properties	Remarks
Phenolic Resins Cast	Unaffected by strong acids	Decomposed by 1% NaOH	Reliable to 225°F for insulation	
Molded	Surface roughened by strong mineral acids. Unaffected by 5% acetic acid	Decomposed by 10% NaOH, surface discoloration by 10% NH_4OH	Reliable to 225°F	
Laminated	Edges swollen by mineral acids and 5% acetic acid	Delaminated by 10% NaOH	Reliable to 225°F	Used extensively for structural insulation and spacers
Urea Formaldehyde Molded	Deteriorated by mineral acids	Not affected by alkali	Reliable to 225°F	
Laminated	Delaminated by 10% HCl	Not affected by alkali	Reliable to 225°F	
Melamine Formaldehyde Laminated Glass Filler	Good	Not affected by alkali	Excellent thermal resistance	Used largely in structural parts for higher temperature uses
Aniline Formaldehyde Unfilled Sheet	Excellent	Not affected by alkali	Distortion pt. 210°F (10 mil. deflection under a 5-lb weight)	

* From "Synthetic Materials Now Utilized for Electric Insulation," by C. H. Braithwaite, Jr., *Industry and Power*, February 1946, Vol. 50.

TABLE 4*
THERMOPLASTIC INSULATING MATERIALS

Material	Softening Point	Insulation Uses	Physical Characteristics
Poly Vinyl Chloride	150-180°F	Used as a wire or cable insulation	Hard, high softening point
Poly Vinyl Acetate	100-140°F	Wide use as adhesive	Soft, low softening point
Polythylene	220°F	Widely used as cable insulation. Extremely low electrical losses	Can be obtained as film or fiber. T.S. = 1900p.s.i.
Polystyrene	165-190°C	Many moderate temperature structural purposes. Limited chiefly by low softening point. Used as coil form material	Hard, tough, transparent plastic. Power factor = .0001 to .0004; dielectric constant = 2.5; ASTM arc resis. 120-140 sec.; vpm = 500-700
Nylon FM-1	Greater than 400°F	Used as fiber for extruded insulated wire covering, and for coil forms	High tensile strength (15,700p.s.i.). Heat transfer 1.74 Btu/hr/ft²/op/in.
Lucite (methyl-methanylite)	140-185°F	Limited to low temperature uses—largely structural	Clear plastic low abrasion resistance. Tough and flexible
Ethyl Cellulose	120-200°F	Used as hot dipped moisture-proofing coating on small pieces for export shipment	Tough, film forming, low melting point
Saran (Vinylidene chloride)	240-280°F	Used where chemical resistance is important	Excellent chemical resistance. Obtainable as sheet, rods or tubes. Sp. gr. 1.70; dielectric strength = 500-3000vpm; dielectric constant = 4 (60 cycles); power factor = .03-.08
Cellulose Acetate	160°F	Used as turn and ground insulation. Particularly on small coils	Transparent substances often pigmented. Usually supplied as film or tape. Density 1.27 to 1.56 gm/cm³

* From "Synthetic Materials Now Utilized for Electric Insulation," by C. H. Braithwaite, Jr., *Industry and Power*, February 1946, Vol. 50.

Table 5*
Varnishes and Adhesives

Chemical Generic Name	Composition	Uses	Properties
Alkyds	Polymers of polybasic acids and polyhydric alcohols—best known example phthalic acid and glycerol (glyptol varnish) May be modified with other resins or oils	Electrical insulating varnish particularly good for dipping. Some alkyds are used for synthetic mica bonds. Used in iron oxide filled (red) insulating enamels	Good adhesion to mica and glass surfaces. Readily absorbed by cotton. May be either thermoplastic or thermosetting depending upon chemical constituents. Phthalic acid - glycerol polymers (glyptal) are thermoplastic and notable for their good film forming characteristics Modification with phenolic resin imparts better moisture characteristics, and thermosetting properties
Polyvinyl Acetate		Adhesive	Readily soluble in alcohol, acetone, may be hot pressed. Good thermoplastic adhesive
Vinyl Copolymers, Fosterite, Allyl Resins, etc.	The solvent in these varnish-like resins enters into the polymerization reaction thus reducing the vessiculation hazard due to loss at solvent	Electrical insulating impregnates varnishes, and as encapsulations for electrical devices	Excellent moisture resistance, good electrical properties. This classification includes most modern "solventless" type electrical insulating varnishes
Silicone Resins	Polymers with a silicone oxygen chain as a backbone in place of the usual carbon chain for organic resins. The side chains are usually organic, thus classifying this series as organic-metallic compounds	1) Electrical insulating varnishes 2) Mica bonds 3) Temperature resisting rubber 4) High temperature greases 5) Oils with minimum changes in viscosity over large changes in temperature	This classification includes an entire family of chemical compounds and mixtures. Some are characterized by excellent moisture resistant properties
Urea Formaldehyde		1) As coating material. Must be modified with other film forming materials to be practical. These resins are hard, brittle, and lack adhesion unless modified	Good color quality and low temperature baking schedules

* From "Synthetic Materials Now Utilized for Electric Insulation," by C. H. Braithwaite, Jr., *Industry and Power*, February 1946, Vol. 50.

Table 6*
Physical Properties of Glass Fabric-Base Laminated Phenolic Compared with Paper-Base and Asbestos-Base Laminated Phenolics

	Glass Fiber Base	Paper Base	Asbestos Cloth Base
Tensile strength (p.s.i.)	14 000-20 000	7 000-18 000	7 000-12 000
Flexural Strength (p.s.i.)	20 000-27 000	13 000-30 000	10 000-35 000
Modulus of Elasticity (p.s.i. $\times 10^5$)	10-20	4-20	3.5-15
Impact Strength Notched Izod ft lb per in.	5.0-6.5		
Water Absorption 24 hr Immersion, %	0.3-0.5	0.3-9.0	0.3-2.0
Specific Gravity	1.4-1.6	1.3-1.4	1.55-1.8
Dielectric Constant, 10^6 Cycles	3.7-5.5	3.6-5.5	7.5
Dielectric Strength, 60 cycles (short-time test), vpm	450-650	400-1000	60-150

* From "Chemical Fibers Find Use in Many Electrical Components," by D. L. Gibson, *Electrical Manufacturing*, March 1945, Vol. 35.

Table 7*
Properties of Dielectrics

Material	Dielectric Constant	Dielectric Strength, kv/cm	Thickness of Sample	Resistivity, ohm-cm	60 cycles, Power Factor, percent
Air	1.0006	30.0	25 mm	......	....
Transformer Oil	2.13	135.0	0.1 in.	7×10^{12}	0.5 to 2.0
"Pyranol"	4.50	110	....	3×10^{12}	0.3 to 14.0
Vinyl	4.0	80 to 200	....	10^{14}	....
Phenolic	4.8	75 to 180	....	0.1×10^{10}	4 to 20
Casein	4.3 to 8.3	160 to 280	....	......	....
Acrylic	2.8 to 3.0	190	....	10^{12}	2.0
Urea	6.0	75 to 150	....	2×10^{7}	7.0
Cellulose Acetate	5.0 to 7.0	34	....	4.5×10^{1}	15.3
Cellulose Nitrate	6.7 to 7.3	75 to 250	....	2×10^{10}	6.2 to 14.4
Ethyl Cellulose	3.9	400 to 500	....	......	0.25 to 2.0
Asbestos	...	40	1.0 mm	......	....
Mica	7.0 to 7.3	1 500 to 2 200	2.5 mm	2×10^{13} to 2×10^{17}	0.3
Manila Paper	2.0	25	0.2 mm	......	....
Varnished Paper	2.0	100 to 250	....	......	....
Paraffined Paper	2.0	500	....	......	....
Varnished Cotton	2.0	80 to 300	0.2 mm	......	....
Varnished Linen	...	100 to 200	0.2 mm	......	....

* By permission from "Insulation of Electrical Apparatus," by Douglas F. Miner, McGraw-Hill Book Co., Inc., 1941. (Only those parts of Miner's Table XXIV relevant to this Circular are used.)

TABLE 8*
LAMINATED RESIN TUBING

Material No.	Color	Constituents	Description	Application	Cost Relation	Specific Gravity	Ultimate Strength, lb/sq in.		Dielectric Strength, 1/16-in. Wall, volts/mil		Water Absorption, % Increase in wt After 24 hr in Water	Power Factor, 10^6 Cycles, 20°C
							Tensile	Compression	In Oil	In Oil After 24 hr in Water		
1	Tan	Kraft paper and synthetic resin	Cannot be threaded	For mechanical or electrical use under dry conditions	Cheapest synthetic	1.29	10 000	11 000	700	500	7	
2	Tan	Kraft paper and synthetic resin	Better than 1	Where machining qualities are desirable	Somewhat more expensive than 1	1.29	11 000	20 000	1000	800	3	Less than 3
3	Brown	Kraft paper and shellac	Will not collapse at 100°C. Resists arcing slightly more than synthetic resin materials. It is not baked	For general use under 75°C except brush-holder tubes	Cheapest grade of Kraft paper and shellac insulation	1.12	8 000	7 000	800		55	
4	Brown	Kraft paper and shellac	Will not collapse at 100°F. Resists arcing slightly more than synthetic resin materials	For general use from 75 to 100°C	Slightly higher in cost than 3	1.12	8 000	8 500	800	500	30	
5	Black	Kraft paper and synthetic resin	Similar to 2 except in color; lower dielectrically	Machinability not so good as that of 2	Somewhat less expensive than 2	1.29	11 000	20 000	650	500	3	Less than 3
6	Brown	Express paper and shellac	Will collapse at 100°C unless supported	For tank liners	Cheapest Micarta tubing							
7	Tan	Cotton and synthetic resin	Fine-weave fabric. Has low moisture absorption	Where high impact is desired	High cost	1.25	5 800	22 000	350		2.5	

* By permission from "Insulation of Electrical Apparatus," by D. F. Miner, McGraw-Hill Book Co., Inc., 1941.

TABLE 8 (CONTINUED)
LAMINATED RESIN TUBING

Material No.	Color	Constituents	Description	Application	Cost Relation	Specific Gravity	Ultimate Strength, lb/sq in.		Dielectric Strength, 1/16-in. Wall, volts/mil		Water Absorption, % Increase in wt After 24 hr in Water	Power Factor, 10^6 Cycles, 20°C
							Tensile	Compression	In Oil	In Oil After 24 hr in Water		
8	Tan	Cotton and synthetic resin	Coarser weave fabric than 7. Below 1 in. use 7	Supplied only in 1 in. i.d. and above	10% cheaper than 7	1.25	6 500	15 000			6	
9	Tan	Sulphite paper and synthetic resin	Good mechanical properties. Does not punch. Best electric material for humid conditions. Best paper base for heavy walls	General electrical use under humid condition	More expensive than 2	1.32	7 500	10 000	750	650	2	Less than 3
10	Tan	Cotton and special synthetic resin	Hard dense material. Special tungsten carbide tools required for machining	Light-duty bearings of 360-deg segment only	High fabrication cost							
11	Tan	Sulphite paper and synthetic resin	Best punching material. Good machining. Not made in wall thickness over ⅛ in.	For radio-coil forms only	Most expensive paper tubing	1.32	7 800	10 000	650	550	3	3.2
12	Tan	Asbestos cloth and synthetic resin	Primarily for good heat resistance	Welding electrode insulation	Fairly expensive							
13	Tan	Asbestos cloth and synthetic resin	Somewhat inferior to 12	Primarily for good heat resistance	Cheaper than 12 tubing							
14	Tan	Cotton and synthetic resin	Fine-weave fabric. Lowest moisture absorption and best for chemical application	Lower in strength than 7	High cost							

TABLE 8 (CONCLUDED)
LAMINATED RESIN TUBING

Material No.	Color	Constituents	Description	Application	Cost Relation	Specific Gravity	Ultimate Strength, lb/sq in.		Dielectric Strength, 1/16-in. Wall, volts/mil		Water Absorption, % Increase in wt After 24 hr in Water	Power Factor, 10^6 Cycles, 20°C
							Tensile	Compression	In Oil	In Oil After 24 hr in Water		
15	Red-brown	Glass fiber and phenolic resin	Staple or continuous or mat	For uses requiring high tensile, flexural, compressive and impact strengths with good electrical properties	1½ to 2 times cotton phenolic	1.4-1.8	11 500-40 000	42 000-47 000			0.3-3.0	0.01-0.03
16	Gray	Glass fiber and polyester resins	Staple or continuous or mat impregnated or saturated with polyester thermosetting (low pressure) resins	Excellent machining and punching properties with good resistance to elevated temperatures. Good electrical and mechanical properties	About 10% higher than cotton phenolic	1.45	20 000	20 000			0.319	
17	Gray	Glass fiber and melamine resin	Staple or continuous or mat impregnated with melamine resins	More water and heat resistant than the phenolics. Used where high heat resistance, high arc resistance, and high mechanical strength are needed	1 to 2 times higher than glass phenolic	1.65-1.95	40 000-50 000	30 000-97 000			0.9-1.3	0.011-0.013
18	Gray-brown	Glass fiber and silicone resin	Staple or continuous or mat impregnated with silicone resin (thermosetting bonding agent)	High heat stability and waterproofness. Used in equipment where ambient temperatures are high or where overload insurance is desired	About twice glass melamine	1.6-1.8	10 000-25 000	35 000-46 000			0.15-0.65	0.0012-0.0015

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Detailed Chart (Continued)

Rating of 1—best characteristic; rating of 10—poorest characteristic but still usable

MAGNET WIRE

Material	Motors and Generators	Transformers	Dielectric Strength, vpm	Build-up, mils*	Abrasion (resistance to)	Flexure (life under)	Elongation	Bend (continuity of insulation under)	Handability	Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to: Moisture	Resistance to: Oil	Resistance to: Acid	Resistance to: Base	Resistance to: Solvent	Stripping (ease of): Chem.	Stripping (ease of): Mech.
Synthetic Enamel	Single	Formvar and nylon film	3	1 2.0	1-9	Do not think this property applicable to magnet usage. No data on this property; conductor would fail under this test before insulation unless flexing bend is very sharp. In latter event see ratings under bend test	Elongation depends on temper of conductor and on wire size and on large conductors. None of the insulators materially decrease elongation but on smaller wires—glass, silk, nylon, cotton, and felt—will affect elongation downward	1	1	3 105°C	2-4	1	1-4	All constructors are resistant to and unaffected by mineral oils and no data on relative resistance	4	3-5	4-6	1-4	1
	Heavy	Heavy formvar or heavy nylon film	2	2 4.0	1-8			1	1	3 105°C	2-4	2	1-3		3-4	3	3-5	2	3
	Triple	Triple formvar or triple nylon film	1	3 5.1	1-4			1	1	3 105°C	2-4	3	1-2		2-4	2-3	2-4	3	4
	Quadruple	Quad. formvar or quad. nylon film	1	5 6.8	1-3			1	1	3 105°C	2-4	4	1		1-4	1-3	1-3	4-5	5
	Single or double nylon	Formvar and yarn or nylon film	6	4	4			2	2	2	3	5	3		5	4	2		6
	Single or double silk	Formvar silk or nylon film and silk	4	4	5			2	2	2	3	5	3		6	4	1		5
	Single paper	Formvar paper or nylon film paper	7	4	6			3	3	2	4	5	4		7	6	1		3
	Single or double cotton	Formvar cotton or nylon film cotton	9	8	1			2	2	2	5	6	4		7	6	1		2
	Single or double glass	Formvar glass or nylon film glass	5	6 4.0-9.0	3-4			2-3	4-6	1 130°C	1-2	3-5	2-4		2-3	3-7	1-4		3-7
	Asbestos	Formvar and asbestos varnish or nylon film asbestos varnish	10	9	7			5	5	1	1	7	5		3	8	1		5
	Cellophane	Formvar and cellophane or nylon film and cellophane	7	4	6			3	2	2	5	5	5		7	6	1		3
	Cotton over paper	Formvar paper and cellophane or nylon film and paper and cotton	8	7	3			4	3	2	4	6	5		7	6	1		3
Conventional Enamel	Single	Enamel	9	1-2 0.8-2.0	4-10			1-3	1	3	6	1-2	1-9	5	3-5	4-5	5-8	1	1
	Heavy	Enamel	1	1-2 1.5-4.0	3-10			2	1	3	5-6	2-3	1-3	4	1-4	1	4-8	3	2
	Single or double nylon	Enamel and nylon	3	3	3			3	2	2	4	3	3	2	5	2	3		6
	Single or double silk	Enamel and silk	3	3	4			3	2	2	3	3	3	2	5	2	3		5
	Single paper	Enamel and paper	4	3	5			3	3	2	2	3	5	2	6	3	3		4
	Single or double cotton	Enamel and cotton	8	5	1-3			2-5	1-4	2	5-6	4-5	5-6	3-6	5-6	3	3-6		1-3
	Single or double glass	Enamel and glass	2	4	3			4	4	1	1	3	2	1	2	5	2		7
	Asbestos	Enamel and asbestos and asbestos varnish	7	7	5			6	5	1	1	6	8	1	4	5	All are resistant to organic solvents		5
	Cellophane	Enamel and cellophane and enamel	5	3	5			3	2	2	5	3	6	3	6	3			4
	Cotton over paper	Enamel and paper and cotton	6	6	2			5	3	3	4	5	7	2	6	3			4
Bare Copper	Single or double silk	Unsaturated; plain	5-6	1	5-6			1	1	90°C	2	1	9-10	See note above	3	1			2
		Saturated; finished	3-4		5-6					105°C			5-6						
	Single or double nylon		4	1	2			1	1	2	2	2	3		2	1			
	Single paper	Unsaturated; plain	7-8	2	7-8			4	2	90°C	3	3	9-10		4	2			6
		Saturated; finished	5-6		3-4					105°C			5-6						
	Single or double cotton	Unsaturated; plain	9-10	4	5-6			2	1	90°C	4	4	9-10		4	2			1
		Saturated; finished	5-6		3-4					105°C			5-6						
	Asbestos	Asbestos varnish	2-8	5	1-7			6	5	1	1	7	2-8		1	5			7
	Cellophane	Cellophane and enamel	7-8	2	5-8†			3	2	2	5	3	5-8		4	3			5

	Cellophane	Enamel and cellophane and enamel	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	6	3			4
	Cotton over paper	Enamel and paper and cotton	6	6	2			5	3	3	4	5	7	2	6	3			4
Bare Copper	Single or double silk	Unsaturated; plain Saturated; finished	5-6 3-4	1	5-6 5-6	Do not think this proper... this test before insulatio...	Elongation depends on tem... rially decrease elongation b...	1	1	90°C 105°C	2	1	9-10 5-6		3	1	All are resistant to organic solvents		2
	Single or double nylon		4	1	2			1	1	2	2	2	3		2	1			
	Single paper	Unsaturated; plain Saturated; finished	7-8 5-6	2	7-8 3-4			4	2	90°C 105°C	3	3	9-10 5-6	See note above	4	2			6
	Single or double cotton	Unsaturated; plain Saturated; finished	9-10 5-6	4	5-6 3-4			2	1	90°C 105°C	4	4	9-10 5-6		4	2			1
	Asbestos	Asbestos varnish	2-8	5	1-7			6	5	1	1	7	2-8		1	5			7
	Cellophane	Cellophane and enamel	7-8	2	5-8†			3	2	2	5	3	5-8		4	3			5
	Cellulose acetate		5-6		7-8†					105°C			5-6						
	Cotton over paper	Paper and cotton	5	6	4			3	3	2	3	5	7		4	2			4

* Rated on basis of space factor (or coils moved) of the wire; the thinner the insulation the better the space factor.
† Very resistant to petroleum and coal tar solvents. Soluble in most lacquer solvents.

COMPOSITE MICA SHEETS AND TAPES

Material	General Remarks	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Creasing (resistance to)	Tear (resistance to)	Tensile (Breaking) Strength, lb/in. width	Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to*: Moisture	Oil	Acid	Base	Solvent
Conventional Varnish—Backed With:																
Jap Paper Jap Paper		Dielectric strength depends on quality of mica used, and how much. (Approximately 300 to 500 vpm)	3.0 to 6.0	8-9	5-9	7-10	7-8	8	Limited by decomposition (char) temperature of paper 5 105°C	4-8	8	8	6	9		8
Rope Paper Rope Paper			3.0 to 6.0	6-9	5-9	6-10	7	7	5 105°C	4-8	8	8	6	9		8
Jap Paper Rope Paper			Jap and rope papers may be used interchangeably								No appreciable difference					
Jap Paper Fish Paper			10.0 to 12.0	8	7	4	5	5	4	6						
Jap Paper Cotton			5.5 to 7.5	6	2	5	6	6	4	5						
Jap Paper Rayon			5.0	7	1	5	4	4	4	5						
Jap Paper Glass			5.5 to 8.0	4	3	2	2	wrp. 65; fil. 35	3	4						
Backing Material, Using Organic Varnish																
Cellophane			5.0 to 15.0	9	5	8	9	5	6 105°C							
Glass	Basis for rating— .002 treated cloth .004 mica	900-1000	4.0 to 11.5	5	3-4	3-9	3	wrp. 65; fil. 35	2 180°C	2	7	2	2	3	3	4
Glass Glass	Basis for rating— .002 untreated cloth .004 mica .002 treated cloth	1000-1191	6.0 to 15.0	1-5	2-3	1-9	1-3	wrp. 100; fil. 70	2 180°C	2	7	2	2	3	3	4
Asbestos Asbestos	Machine-built mica center .008-.015 thk.		60.0 to 125.0	5-8	6-9	6-9	8	9	3 130°C	2-3	9	6	7	9		9
Silicone Varnished—Backed With:																
Glass	(Tape, backed one side only)	1000	3.5	5	4	9	3	wrp. 40	180°C	1-2	9	2	10	5		9
Glass	Treated paper one side	400-600	3.4 to 7.5	3-5	3-4	3-9	3	wrp. 40 to 65; fil. 10 to 35	1 180°C+	1-2	9	2	10	5		9
Glass Glass		400-700	9.5 to 15.0	1-5	1-3	1-8	1-3	wrp. 90 to 100; fil. 60 to 70	1 180°C+	1-2	9	2	10	5		9
Asbestos Asbestos (paper form)	Machine-built mica center	500	60.0 to 125.0	8-9	8-9	6-8	8-9	9	1 180°C+	1-4	9	5	10	5		9
Unbacked Mica:																

Asbestos Asbestos	Machine-built mica center .008-.015 thk.		60.0 to 125.0	5-8	6-9	6-9	8	9		3 130°C	2-3	9	6	7	9		9
Silicone Varnished—Backed With: Glass	(Tape, backed one side only)	1000	3.5	5	4	9	3	wrp. 40		180°C	1-2	9	2	10	5		9
Glass	Treated paper one side	400-600	3.4 to 7.5	3-5	3-4	3-9	3	wrp. 40 to 65	fil. 10 to 35	1 180°C+	1-2	9	2	10	5		9
Glass Glass		400-700	9.5 to 15.0	1-5	1-3	1-8	1-3	wrp. 90 to 100	fil. 60 to 70	1 180°C+	1-2	9	2	10	5		9
Asbestos Asbestos (paper form)	Machine-built mica center	500	60.0 to 125.0	8-9	8-9	6-8	8-9	9		1 180°C+	1-4	9	5	10	5		9
Unbacked Mica: Mica Sheet	Hand built	700	7.0 to 30.0	10	9	10	9	9		1 180°C+	2						
	Machine built	500	5.0 to 15.0	10	10	9	10	10		1 180°C+	2						
Uncut Mica	Segment mica-shellac	1000	1.0	3	9	10	2			180°C+	2	7	4	2	6	9	3*
	Block mica	1500		4	9	10				180°C	1	5	2	2	2	3	1

* No resistance to alcohol. For the last two types of material in this part of the chart, these characteristics are dependent on the type of treatment applied to the covering materials rather than on the base covering fabric or the type of binder employed.

MISCELLANEOUS FABRICS (SHEETS AND TAPES), VARNISHED AND UNVARNISHED)

Duck Sheet Black Varnished				3	3	5	2			105°C	5	8	8	8			9
Rayon or Sheet Tape Yellow Varnished			2.5 to 8.0	3	4	4	8	wrp. 25	fil. 25	105°C	5	8	3	3			6
Silk Varnished Straight		1400 to 1900	2.0 to 8.0	3	4	4	8	wrp. 20		105°C	5	8	3	2			6
Silk Varnished Bias		1400 to 1900	2.0 to 8.0	3	4	4	6	wrp. 20		105°C	5	8	3	2			6

PAPER SHEETS AND TAPES

Material	General Remarks	Power Factor 30°C	Power Factor 60°C	Power Factor 100°C	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Creasing (resistance to)	Tear (resistance to)	Handability	Tensile (Breaking) Strength, lb/in. width		Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to Moisture	Oil	Acid	Base	Solvent
Condenser	Kraft (hot washed)	.160	.155	.225		0.475 to 0.525	8	4	6	4	3			105°C	7	5	8	4	9	9	4
		.160	.155	.225		0.7 to 0.8															
	Kraft (cold washed)	.160	.155	.225		0.275 to 0.325															
		.160	.155	.225		1.9 to 1.1															
Bond						2.5 to 3.5	2	4	7	3	3	MD 25	CMD 15	105°C	5	5	8	4	9	9	4
Kraft					400 250 160	0.9 to 1.1 2.8 to 3.2 4.7 to 5.3	9	4	5	4	3	MD 250	CMD 260	105°C	7	5	8	4	9	9	4
Rope						0.9 to 1.1 1.8 to 2.2 4.5 to 5.5	7	4	4	3	3	MD 10.5 27 70		105°C	6	5	8	4	9	9	4
Fish Paper					300 300 150	4.0 to 6.0 13.0 to 17.0 116.0 to 134.0	6	4	6	3	3	MD 12 187 1800	CMD 31 93 940	105°C	7	5	8	4	9	9	4
Rag 100%					460 400 300	6.5 to 7.5 14.0 to 16.0 23.0 to 27.0	4	4	4	3	3	MD 350 800 1250	CMD 500 1400 1600	105°C	7	5	8	4	9	9	4

No.	Type	Application	Color	Supplied at Specific Gravity	Baumé	Specific Gravity for Application	Solids by Weight	Average Short Time Dielectric Strength, vpm	Recommended Curing Time: Bake	Recommended Curing Time: Air	Solvent	Resistance to: Oil	Resistance to: Moisture	Resistance to: Acids	Resistance to: Alkalies	Resistance to: Heat
512-C	Harvel Internal drying baking varnish	Any application requiring excellent insulating characteristics, internal drying and high mechanical strength. This varnish is ideally suited to the impregnation of wound stators and rotors, rotating fields and air-cooled transformers. Special notice should be taken of the extreme resistance of this varnish in its cured state to acids and alkalies	Mahogany	.861 at 30°C	32½ at 30°C	As supplied	52 to 55%	2100	12 to 15 hr at 250°F 10 to 12 hr at 275°F		V.M. & P. Naphtha Distillation range 220-300°F	Fair	Good	Excellent	Excellent	Good
612-C	Harvel Internal drying baking varnish	This varnish produces the same general characteristics of 512-C, affording, however, greater oil resistance and shorter curing time	Dark Mahogany	.869 at 30°C	31° at 30°C	Optional	55 to 59%	2300	10 to 14 hr at 250°F 6 to 9 hr at 275°F		V.M. & P. Naphtha Distillation range 220-300°F	Good	Good	Excellent	Excellent	Good
912-C	Harvel Internal drying baking varnish	Harvel 912-C produces in general the same characteristics as 512-C and 612-C. It is, in addition, absolutely oilproof and affords extreme bonding and mechanical strength even at high operating temperatures and high peripheral speeds. Harvel 912-C is faster curing than either 512-C or 612-C	Dark mahogany	.872 at 30°C	30½° at 30°C	Optional	55 to 60%	2200	6 to 8 hr at 220°F 4 to 6 hr at 250°F 2 to 4 hr at 275°C		Same as above	Excellent	Good	Excellent	Excellent	Good
100	Irvington Internal drying clear baking varnish	Irvington No. 100 clear baking varnish is outstanding in the clear internal drying varnish field for its clarity, extreme heat endurance, lead flexibility and storage stability. It can be used wherever an internal drying varnish having these characteristics is required	Light yellow	.859 at 30°C	33° at 30°C	Optional	48 to 53%	2250	6 to 8 hr at 250°F 4 to 6 hr at 275°F		Same as above	Excellent	Excellent	Good	Fair	Excellent
200	Irvington Internal drying clear baking varnish	A less expensive clear internal drying baking varnish which has the same general properties as No. 100. It is recommended for similar applications, where cost is of first importance	Light amber	.840 at 30°C	36½° at 30°C	As supplied	43%	2100	6 to 8 hr at 250°F 4 to 6 hr at 275°F		Same as above	Very good	Very good	Good	Fair	Very good
500	Irvington Internal drying black baking varnish	No. 500 varnish can be used in any application requiring a black internal drying varnish affording maximum protection. No. 100 and 500 have exceptional metal adhesion	Black	.869 at 30°C	31° at 30°C	Optional	48 to 53%	2100	6 to 8 hr at 250°F 4 to 6 hr at 275°F		Same as above	Good	Good	Good	Fair	Very good
202	Harvel Clear baking varnish	Harvel 202 is applicable to armature and field coils, wound armature and stators, oil immersed transformers, windings and any other application requiring extreme resistance and durability in a non-polymerizing type varnish, having extreme flexibility	Deep brown	.895 at 20°C	26½° at 20°C	Optional	56 to 60%	2100	8 to 12 hr at 220°F		V.M. & P. Naphtha	Excellent	Excellent	Good	Very good	Good
602	Harvel Black baking varnish	Harvel 602 is ideally suited for application to railway, mining, and other heavy duty apparatus for form wound coil and wherever prolonged flexibility and resistance to deleterious agents and heat is required	Black	.889 at 20°C	27½° at 20°C	Optional	53 to 56%	2100	8 to 12 hr at 220°F		V.M. & P. Naphtha	Good	Excellent	Good	Very good	Good
1	Irvington Clear baking varnish	Irvington No. 1 Clear Baking Varnish is recommended for use on armature and field coils before assembly; for impregnated armatures and stators, transformer and instrument coils and for any other application in which its flexibility and protection are of value	Light amber	.895 at 20°C	26½° at 20°C	Optional	58 to 62%	2150	6 to 10 hr at 220°F		Same as above	Good	Good	Good	Fair	Good
5	Irvington Black baking varnish	An excellent varnish for treating assembled armatures and stators and coils where mechanical properties, high dielectric strength, and resistance to deleterious agents is desired in a non-internal curing type of varnish	Black	.875 at 20°C	30° at 20°C	Optional	48 to 50%	2300	6 to 10 hr at 220°F		Same as above	Fair	Good	Very good	Very good	Fair
121	Irvington Clear baking varnish	An inexpensive clear baking varnish for application to coils and assembled windings requiring the characteristics of this type varnish	Light amber	.886 at 20°C	28° at 20°C	As supplied	45%	2400	1 hr at 250°F		Same as above	Good	Good	Fair	Fair	Very good
517	Irvington Black baking varnish	An inexpensive black baking varnish similar to No. 121, used on coils and assembled windings	Black	.869 at 20°C	31° at 20°C	As supplied	45%	2000	3 hr at 250°F		Same as above	Good	Good	Fair	Fair	Very good
		Air-Drying Varnishes														
902	Harvel	This varnish can be applied to any winding regarding high insulating characteristics where baking facilities are not available and due to its unusual flexibility and heat endurance it can also be used as a quick baking varnish	Mahogany	.875 at 20°C	30° at 20°C	Optional	47 to 52%	1000		8 hr at 68°F	Same as above	Good	Good	Very good	Good	Very good
1301	Harvel	Harvel 1301 is widely used as a final coat on wound apparatus to increase protection and enhance appearance, and it is also used by cable manufacturers as a saturant for cotton braid. Due to its extreme metal adhesion it is also used for painting	Black	.875 at 20°C	30° at 20°C	Optional	48 to 52%	1650		8 hr at 68°F	Same as above	Good	Good	Very good	Good	Very good

202	Harvel Clear baking varnish	Harvel 202 is applicable to armature and field coils, wound armature and stators, oil immersed transformers, windings and any other application requiring extreme resistance and durability in a non-polymerizing type varnish, having extreme flexibility	Deep brown	[illegible] at 20°C	[illegible] at 20°C	[illegible]	[illegible] 60%	[illegible]	[illegible] at 220°F	[illegible] Naphtha	[illegible] lent	[illegible] lent	[illegible]	[illegible] good	Good
602	Harvel Black baking varnish	Harvel 602 is ideally suited for application to railway, mining, and other heavy duty apparatus for form wound coil and wherever prolonged flexibility and resistance to deleterious agents and heat is required	Black	.889 at 20°C	27½° at 20°C	Optional	53 to 56%	2100	8 to 12 hr at 220°F	V.M. & P. Naphtha	Good	Excellent	Good	Very good	Good
1	Irvington Clear baking varnish	Irvington No. 1 Clear Baking Varnish is recommended for use on armature and field coils before assembly; for impregnated armatures and stators, transformer and instrument coils and for any other application in which its flexibility and protection are of value	Light amber	.895 at 20°C	26½° at 20°C	Optional	58 to 62%	2150	6 to 10 hr at 220°F	Same as above	Good	Good	Good	Fair	Good
5	Irvington Black baking varnish	An excellent varnish for treating assembled armatures and stators and coils where mechanical properties, high dielectric strength, and resistance to deleterious agents is desired in a non-internal curing type of varnish	Black	.875 at 20°C	30° at 20°C	Optional	48 to 50%	2300	6 to 10 hr at 220°F	Same as above	Fair	Good	Very good	Very good	Fair
121	Irvington Clear baking varnish	An inexpensive clear baking varnish for application to coils and assembled windings requiring the characteristics of this type varnish	Light amber	.886 at 20°C	28° at 20°C	As supplied	45%	2400	1 hr at 250°F	Same as above	Good	Good	Fair	Fair	Very good
517	Irvington Black baking varnish	An inexpensive black baking varnish similar to No. 121, used on coils and assembled windings	Black	.869 at 20°C	31° at 20°C	As supplied	45%	2000	3 hr at 250°F	Same as above	Good	Good	Fair	Fair	Very good
		Air-Drying Varnishes													
902	Harvel	This varnish can be applied to any winding regarding high insulating characteristics where baking facilities are not available and due to its unusual flexibility and heat endurance it can also be used as a quick baking varnish	Mahogany	.875 at 20°C	30° at 20°C	Optional	47 to 52%	1000	8 hr at 68°F	Same as above	Good	Good	Very good	Good	Very good
1301	Harvel	Harvel 1301 is widely used as a final coat on wound apparatus to increase protection and enhance appearance, and it is also used by cable manufacturers as a saturant for cotton braid. Due to its extreme metal adhesion it is also used for painting switch bosses and battery trays. An excellent maintenance varnish	Black	.875 at 20°C	30° at 20°C	Optional	48 to 52%	1650	8 hr at 68°F	Same as above	Good	Good	Very good	Good	Very good
9	Irvington	Recommended for treating coils and assembly apparatus where baking is impractical or baking facilities unavailable	Clear amber	.870 at 20°C	31° at 20°C	Optional	48 to 53%	2000	3 hr at 68°F	Same as above					
908	Irvington	An inexpensive clear air drying varnish, similar in character to No. 9, and recommended for the same types of work	Light amber	.895 at 20°C	27° at 20°C	Optional	46 to 57%	900	4 hr at 68°F	Same as above	Good	Good	Good	Good	Fair
1201	Irvington	Recommended for quick repair and maintenance and for painting metallic surfaces, conduit boxes, switch and signal boxes, storage battery trays and racks. It is also used as a surface coat over previously impregnated windings	Black	.840 at 20°C	36½° at 20°C	Optional	39 to 42%	750	2 hr at 68°F	V.M. & P. Naphtha	Fair	Good	Good	Good	Fair
1208	Irvington	An inexpensive black air drying varnish which is recommended for maintenance work where lower cost is important	Black	.889 at 20°C	28° at 20°C	Optional	49 to 51%	350	2 hr at 68°F	V.M. & P. Naphtha	Fair	Good	Good	Good	Fair
19	Irvington Finishing	An oilproof finishing varnish made from spirit soluble resins recommended as a finishing coat on previously treated windings to improve appearance and provide added protection	Light amber	.920 at 20°C	22° at 20°C	Optional	38 to 40%	700	30 min at 68°F	Denatured Alcohol	Very good	Good	Good	Fair	Fair
20	Irvington Finishing	This varnish is recommended for the same applications as Irvington No. 19 finishings, where a black varnish is required	Black	.920 at 20°C	22° at 20°C	Optional	38 to 40%	475	30 min at 68°F	Denatured Alcohol	Good	Good	Good	Fair	Fair
21	Irvington Finishing	A superior finishing varnish based on bleached shellac for improved appearance and additional protection	Light amber	.940 at 20°C	19° at 20°C	Optional	34 to 36%	750	30 min at 68°F	Denatured Alcohol	Excellent	Good	Good	Fair	Fair
22	Irvington Finishing	Similar to No. 21, used where a black varnish is desirable	Black	.918 at 20°C	22½° at 20°C	Optional	38 to 40%	1150	30 min at 68°F	Denatured Alcohol	Excellent	Good	Good	Fair	Fair
2003	Irvington Finishing	An inexpensive black finishing varnish for use as a finishing coat over treated windings	Black	.990 at 20°C	11° at 22°C	Optional	50 to 51%	1150	30 min at 68°F	Denatured Alcohol	Good	Fair	Good	Fair	Fair
2501	Irvington Finishing	An excellent adhesive varnish for cementing cloth, paper and mica	Light amber	.976 at 20°C	13½° at 20°C	Optional	50 to 51%	1400	30 min at 68°F	Denatured Alcohol	Good	Fair	Good	Fair	Fair
2505	Irvington Sticking	Recommended for cementing cloth, paper and mica where adhesion is of primary importance	Light amber	1.00 at 20°C	10° at 20°C	Optional	63 to 66%	750	30 min at 68°F	Denatured Alcohol	Good	Good	Good	Fair	Fair

NOTE: Chart used with permission of the Irvington Varnish and Insulator Company, Irvington, N.J., and the P. D. George Company, St. Louis, Missouri.

Detailed Chart

Rating of 1—best characteristic; rating of 10—poorest characteristic but still usable

ASBESTOS

Material	General Remarks	Dielectric Strength, vpm	Thickness, mils	Abrasion (resistance to)	Flexure (life under)	Creasing (resistance to)	Tear (resistance to)	Tensile (Breaking) Strength, lb/in. width		Maximum Operating Temperature	Thermal Aging	Heat Conductivity	Resistance to: Moisture	Oil	Acid	Base	Solvent
Cloth Sheets and Tapes Unvarnished		50-100	26.0 to 46.0	8	3	5	7	wrp. 50 to 70	fil. 32.5	130°C	2	10	10	7	8		7
Paper Sheets and Tapes Standard Treated				5	7	9	9			130°C	5	10	8	4	9		9
Standard Untreated				10	8	10	10			130°C	3	10	10	4	9		9
COTTON FABRICS (TAPES AND SHEETS), VARNISHED AND UNTREATED																	
Yellow Varnished, Straight		800-1400	4.5 to 6.0	6	4	4	6	40		105°C	6	8	7	4	9	9	4
Yellow Varnished, Bias		950-1250	6.0 to 12.0	6	4	4	4	45		105°C	6	8	7	4	9	9	4
Black Varnished, Straight		1100-1400	9.0 to 13.0	5	4	3	6	57 to 60		105°C	6	8	6	5	9	9	6
Black Varnished, Bias		1200-1500	6.5 to 16.0	5	4	3	4	48 to 50		105°C	6	8	6	5	9	9	6
Unvarnished, Standard Straight		9-10		5-6	7-8					90°C			9-10				1-2
GLASS SHEETS AND TAPES																	
Unvarnished Straight		80	1.5 to 15.0	7	3	7	1	wrp. 100 to 400	fil. 70 to 290	300°C	1	9	1	1	2	4	1
Yellow Varnished, Standard		Dielectric strength varies with over-all thickness and with thickness of varnish film. Values around 1000 vpm are to be expected.	3.0 to 30.0	4	3	9	3			130°C	4	7	1	1	2	4	1
Yellow Varnished, Bias			3.0 to 30.0	4	3	9	3			130°C	4	7	1	1	2	4	1
Black Varnished, Standard			3.0 to 30.0	3	3	8	2			130°C	3	7	1	2	1	4	3
Black Varnished, Bias			3.0 to 30.0	3	3	8	2			130°C	3	7	1	2	1	4	3
Silicone Varnished, Standard			3.0 to 20.0	5	4	9	4	wrp. 70 to 250	fil. 70 to 200	180°C+	2	7	1	8-10	2	4	8-10
Silicone Varnished, Bias			3.0 to 20.0	5	4	9	4	wrp. 70 to 250	fil. 70 to 200	180°C+	2	7	1	8-10	2	4	8-10

LAMINATES

Material	General Remarks	Dielectric Strength, vpm: Short Time	Step by Step	Insulation Resistance Megohms	Power Factor at 10^6 cps as Received	Dielectric Constant at 10^6 cps as Received	Loss Factor	Arc Resistance, sec	Tensile Strength, p.s.i.: LW	CW	Compress. Strength (flat), p.s.i.	Flex. Strength: LW	CW	Impact Strength: Face	Side	Hardness, Rockwell	Bonding Strength, lb	Cold Flow 0-50°	High Temp.	Ther. Blister Cond. Temp., C	Operating Temperature	Moisture Absorption, % in 24 hr	Acid Resistance	Base Resistance

Material	General Remarks	Short Time	Step by Step	Resist-ance Meg-ohms	at 10^6 cps as Re-ceived	stant at 10^6 cps as Re-ceived	Loss Factor	Resist-ance, sec	LW	CW	Strength (flat), p.s.i.	LW	CW	Face	Side	ness, Rock-well	Strength, lb	Flow 0-50°	High Temp.	Cond. Temp., C	Tem-pera-ture	sorp-tion, % in 24 hr	Resist-ance	Resist-ance
Paper Phenolic	X XP XX XXX XXP XXXP	1 400 to 600	1 250 to 600	3 90 to 5800	5 20.0 to 80.0	5 3.6 to 6.50	5 .08 to .27	10 .4 to .16	8 9000 to 16 000	8 7500 to 12 000	6 26 000 to 42 000	5 13 000 to 30 000	5 12 500 to 22 000	5-10	9-10	100 to 120	2 900 to 1200	1-3	3-4	4 230 to 260	3	3 0.3 to 9.0	3	4
Melamine	MX MXX	6 400 to 700	6 200 to 450	2 50 to 200	8 35.0 to 45.0	8 6.75	9 .29 to .37	2 70 to 100	9 20 000	9 15 000	6 30 000 to 48 000	6 23 000 to 25 000	6 18 000 to 19 000	9-10	10	125	2 900 to 1000	5-8	5-8	3 225 to 250	3	7 2.4 to 3.5	3	2
Cotton Cloth Phenolic	C CF CFL CV CE LELDC	4 150 to 600	4 120 to 400	7 10 to 100	7 .02 to 100.0	7 4.5 to 7.0	7 .22 to .7	10 4	6 9000 to 14 500	6 7500 to 12 000	4 30 000 to 44 000	5 20 000 to 23 500	5 16 000 to 22 000	4-6	4-7	70 to 120	1 1900 to 2200	1-5	3-5	3 210 to 250	3	6 0.3 to 9.0	3	4
Melamine		6 320 to 370	6 280 to 320	2	8 .031 to .047	8 6.2 to 10.0	8	2 120 to 1.75	5	5	4 33 000 to 46 000	5 14 000 to 28 000	5	5	5	110 to 120	1	6	6	2	2	6 0.4 to 1.3	3	4
Polyester		600	540			2.0	.05 to .03	90	7700		16 600	13 300				96						0.84		
Cotton Felt Phenolic		3	3	5	6	6	6	10	6	6	5	5	5	3	3		1	1-4	3-5	4	4	5		
Glass Cloth Phenolic	(GB-128D) G- (GB-261D)	4 300 to 650	4 360 to 390	10 25 to 500	5 10.0 to 30.0	5 3.7 to 6.0	5 .046 to .13	10 4 to 15	15 000 to 24 000	11 000 to 15 000	39 000 to 47 000	21 000 to 22 000	19 000	1-3	1-3	95 to 110	2 1200 to 1500	1-2	3-5	270	5 (140°C)	1 0.3 to 0.6	3 depends on resins used	4
Melamine	(GB-128M) G-	5 350 to 520	5 320 to 380	10 50	8 11.0 to 1.40	8 6.9 to 7.7	8 .094 to .12	2 185 to 125	25 000 to 37 000	22 000 to 33 000	30 000 to 97 000	40 000 to 53 000	38 000 to 45 000	1-3	1-3	120	3 900 to 1750	5-8	6-8	270	3 (160°C)	1 0.45 to 0.9	3-7	3-5
Polyester		600	540			2.0	.05 to .03	15-90	20 000 to 35 000		20 000 to 23 000	37 900 to 40 000				110 to 114		6-8	6-8					
Silicone	Continuous filament	10 250 to 300	10 50 to 250	10 3000	1 1.2 to 1.7	1 2.8 to 4.3	1 .0048	1 228	8 19 000	8 17 000	35 000 to 75 000	32 000 to 44 000	30 000 to 37 000	2-5 2.7	2-5	100	5 900 to 1100	1-4	1-2	260	1 (250°C)	1 0.15 to 0.65	1-7	9-10
Glass Mat Phenolic	GM-4	3 600	3 400	9 175	5 .013	5 3.75	5 .049	10 10	6 6500	6 6200	29 000	6 9000	4 8500	4-6 8	4-6 7.5	.85	1 900	1 1-3	3-5	230	(140°C)	1 0.23	depends on resins used	
Melamine	T36 Type Glass Mat (⅛K)	5 380	5	9 450 70V (after 96 hr at 95% RH) 9	9 .015	8 7.2	8 .11	2 132	6 19 800	6 19 800	18 200 edge- wise	6 32 000	33 000	5-8 7	5-8 7		2 900	5-8	3-5	250	(160°C)	1 2.0 (18 K)	3	3
Polyester*		600	540			2.0	.05 to .07	90	19 000 (93°C)		3900 (93°C)	1300 (93°C)						6-8	6-8					
Silicone		9	9	9	1	1	1	1	7	7	7	7	7	4	4		3	1-4	1		(250°C)	1	1	10
Nylon Cloth Phenolic	MEC-1	5 475	5 375	1 30 000	2 14.0 to 30.0	2 3.5 to 3.9	2 .105	10 15	7 9500	7 3400	5 31 000 to 35 000	6 32 000	6 21 000	1 3	1 5	10	2 700	3 1-2	3-5		(120°C)	1 0.2 to 0.35	3	4
Melamine	MEC-2	450	250	200	.07	3.9	.273	70	14 000	13 000	4000	27 000	24 000	2.5	3	110	500	6-8	6-8			2.0		
Asbestos Paper Phenolic*	A	5 100 to 200	5 60 to 220	7	.115 to .12	5.2 to 7.5	.6 to 1.12	10 4	7 11 000 to 13 000	8 7000 to 10 000	5 36 000 to 41 000	7 18 000 to 25 000	8 16 000 to 18 000	6	7-8	100 to 110	6 900	1	2	2-5 230	2-5	3 0.4 to 2.0	3	4
Melamine	MA	100 to 150	60 to 80	5	.11 to .22	8.0 to 9.6	9	.80	10 000	6000	27 000 to 47 000	17 000	13 000	6-7	8	115	900	3	3	230	2-3	5 1.0 to 4.2	2	1
Polyester		5	5	5				3	7	8	5	7	8	6			6	3	3	2-3	1-3	2		
Silicone		10	10	10				3	9	10	5	9	10	7	8		7	2	1	1-3	2-5	3 0.3 to 8.0	3	4

Phenolic*	A	5 100 to 200	5 60 to 220	7	.115 to .12	5.2 to 7.5	.6 to 1.12	10 4	7 11 000 to 13 000	8 7000 to 10 000	5 36 000 to 41 000	7 18 000 to 25 000	8 16 000 to 18 000	6	7-8	100 to 110	6 900	1	2	2-5 230	2-5	3 0.4 to 2.0	3	4
Melamine	MA	100 to 150	60 to 80	5	.11 to .22	8.0 to 9.6	9	.80	10 000	6000	27 000 to 47 000	17 000	13 000	6-7	8	115	900	3	3	230	2-3	5 1.0 to 4.2	2	1
Polyester		5	5	5				3	7	8	5	7	8	6			6	3	3	2-3	1-3	2		
Silicone		10	10	10				3	9	10	5	9	10	7	8		7	2	1	1-3	2-5	3 0.3 to 3.0	3	4
Asbestos Cloth Phenolic	AA	7 60 to 150	7 45 to 125	9	.15 to .44	6.6 to 7.5	1.12 to 2.99	10 4	6 10 000 to 12 000	7 6500 to 11 000	5 18 000 to 49 000	6 19 000 to 25 000	7 15 000 to 24 000	4-6	4-7	106 to 110	5 1100 to 1800	1	2	2-5 270	2-3	3-6	2	1
Melamine		7 40 to 100	7	9				4	6 9000 to 12 000	7	5 25 000 to 50 000	6 20 000 to 24 000	7	6	7	110 to 115	5	3 3	3 3	2-3				
Polyester		600	540			2.0	.05 to .03	90	7100		18 500	31 000				102						0.56		
Silicone		10 50 to 150	10 50 to 100	10				4	8	9	5 40 000 to 50 000	8 12 000 to 16 000	9	7	8		6	2	1	1-3	1-2	3 1.0 to 1.5	3	4
Asbestos Felt Phenolic	FA-72	70	50					4	21 000	17 000	16 000 to 52 000	38 000	27 000	4	6	115	1400	1	2	225		0.4 to 1.0	3	4
Melamine																		3	3					
Polyester*																		3	3					
Silicone																		2	1					

* One of the more commonly used Polyesters was used for comparison basis.

LEAD WIRE (STRANDED CABLE)

Material	General Remarks	Insulation Resistance	Abrasion (resistance to)	Flexure (life under)	Bend (continuity of insulation under)	Stripping	Maximum Operating Temperature	Thermal Aging	Resistance to Moisture	Oil	Acid	Base	Solvent
Plastic or Rubber													
Plain		2	2	1	1	3	5	3	2	4	2		1
Cotton Braid and Lacquer		4	1	2	2	1	4	4	3	2	3		3
Rayon Braid and Lacquer		3	4	3	3	2	4	4	4	3	4		4
Glass Braid and Lacquer		1	3	4	4	4	3	3	1	1	1		2
Cotton													
Cambric and Cotton Braid		3	2	3	4	4	4	4	3	4	6		4
Multiple Cotton Braid		6	5	4	3	5	5	10	10	10	10		6
Asbestos													
Cambric and Outer Braid of Asbestos		4	2	2	4	8	2	2	6	6	6		3
Glass													
Conventional Varnish, Outer Braid of Asbestos		3	2	2	4	7	2	2	4	5	5		3
Silicone Varnish, Outer Braid of Glass		3	5	6	5	4	1	1	6	5	5		3
Silicone Rubber, Outer Braid of Glass		2	5	6	5	4	1	1	5	4	5		4
Fibrous Wraps													
Nylon Serve or Braid (conventional varnish, shellac)		5	2	4	4	5	3	3	2	2	4		2
Rayon Serve or Braid (conventional varnish, shellac)		4	4	5	5	6	5	4	5	5	6		3
Glass Serve or Braid (conventional varnish, shellac)		3	3	5	5	5	2	2	2	4	6		3

		600	400	100	100.0	7.0	.7		14 500	12 000	44 000	23 500	22 000			120	2200			230		5.0		
Melamine		6 320 to 370	6 280 to 320	2	8 .031 to .047	8 6.2 to 10.0	8	2 120 to 1.75	5	5	4 33 000 to 46 000	5 14 000 to 28 000	5	5	5	110 to 120	1	6	6	2	2	6 0.4 to 1.3	3	4
Polyester		600	540			2.0	.05 to .03	90	7700		16 600	13 300				96						0.84		
Cotton Felt Phenolic		3	3	5	6	6	6	10	6	6	5	5	5	3	3		1	1-4	3-5	4	4	5		
Glass Cloth Phenolic	(GB-128D) G-(GB-261D)	4 300 to 650	4 360 to 390	10 25 to 500	5 10.0 to 30.0	5 3.7 to 6.0	5 .046 to .13	10 4 to 15	15 000 to 24 000	11 000 to 15 000	39 000 to 47 000	21 000 to 22 000	19 000	1-3	1-3	95 to 110	2 1200 to 1500	1-2	3-5	270	5 (140°C)	1 0.3 to 0.6	3 depends on resins used	4
Melamine	(GB-128M) G-	5 350 to 520	5 320 to 380	10 50	8 11.0 to 1.40	8 6.9 to 7.7	8 .094 to .12	2 185 to 125	25 000 to 37 000	22 000 to 33 000	30 000 to 97 000	40 000 to 53 000	38 000 to 45 000	1-3	1-3	120	3 900 to 1750	5-8	6-8	270	3 (160°C)	1 0.45 to 0.9	3-7	3-5
Polyester		600	540			2.0	.05 to .03	15-90	20 000 to 35 000		20 000 to 23 000	37 900 to 40 000				110 to 114		6-8	6-8					
Silicone	Continuous filament	10 250 to 300	10 50 to 250	10 3000	1 1.2 to 1.7	1 2.8 to 4.3	1 .0048	1 228	8 19 000	8 17 000	35 000 to 75 000	32 000 to 44 000	30 000 to 37 000	2-5 2.7	2-5	100	5 900 to 1100	1-4	1-2	260	1 (250°C)	1 0.15 to 0.65	1-7	9-10
Glass Mat Phenolic	GM-4	3 600	3 400	9 175	5 .013	5 3.75	5 .049	10 10	6 6500	6 6200	29 000	6 9000	4 8500	4-6 8	4-6 7.5	.85	1 900	1 1-3	3-5	230	(140°C)	1 0.23	depends on resins used	
Melamine	T36 Type Glass Mat (⅛K)	5 380	5	9 450 70V (after 96 hr at 95% RH) 9	9 .015	8 7.2	8 .11	2 132	6 19 800	6 19 800	18 200 edge-wise	6 32 000	33 000	5-8 7	5-8 7		2 900	5-8	3-5	250	(160°C)	1 2.0 (18 K)	3	3
Polyester*		600	540			2.0	.05 to .07	90	19 000 (93°C)		3900 (93°C)	1300 (93°C)						6-8	6-8					
Silicone		9	9	9	1	1	1	1	7	7	7	7	7	4	4		3	1-4	1		(250°C)	1	1	10
Nylon Cloth Phenolic	MEC-1	5 475	5 375	1 30 000	2 14.0 to 30.0	2 3.5 to 3.9	2 .105	10 15	7 9500	7 3400	5 31 000 to 35 000	6 32 000	6 21 000	1 3	1 5	10	2 700	3 1-2	3-5		(120°C)	1 0.2 to 0.35	3	4
Melamine	MEC-2	450	250	200	.07	3.9	.273	70	14 000	13 000	4000	27 000	24 000	2.5	3	110	500	6-8	6-8			2.0		
Asbestos Paper Phenolic*	A	5 100 to 200	5 60 to 220	7	.115 to .12	5.2 to 7.5	.6 to 1.12	10 4	7 11 000 to 13 000	8 7000 to 10 000	5 36 000 to 41 000	7 18 000 to 25 000	8 16 000 to 18 000	6	7-8	100 to 110	6 900	1	2	2-5 230	2-5	3 0.4 to 2.0	3	4
Melamine	MA	100 to 150	60 to 80	5	.11 to .22	8.0 to 9.6	9	.80	10 000	6000	27 000 to 47 000	17 000	13 000	6-7	8	115	900	3	3	230	2-3	5 1.0 to 4.2	2	1
Polyester		5	5	5				3	7	8	5	7	8	6			6	3	3	2-3	1-3	2		
Silicone		10	10	10				3	9	10	5	9	10	7	8		7	2	1	1-3	2-5	3 0.3 to 3.0	3	4
Asbestos Cloth Phenolic	AA	7 60 to 150	7 45 to 125	9	.15 to .44	6.6 to 7.5	1.12 to 2.99	10 4	6 10 000 to 12 000	7 6500 to 11 000	5 18 000 to 49 000	6 19 000 to 25 000	7 15 000 to 24 000	4-6	4-7	106 to 110	5 1100 to 1800	1	2	2-5 270	2-3	3-6	2	1
Melamine		7 40 to 100	7	9				4	6 9000 to 12 000	7	5 25 000 to 50 000	6 20 000 to 24 000	7	6	7	110 to 115	5	3 3	3 3	2-3				
Polyester		600	540			2.0	.05 to .03	90	7100		18 500	31 000				102						0.56		
Silicone		10 50 to 150	10 50 to 100	10				4	8	9	5 40 000 to 50 000	8 12 000 to 16 000	9	7	8		6	2	1	1-3	1-2	3 1.0 to 1.5	3	4
Asbestos Felt																								

Glass Cloth Phenolic	(GB-128D) G- (GB-261D)	4 300 to 650	4 360 to 390	10 25 to 500	5 10.0 to 30.0	5 3.7 to 6.0	5 .046 to .13	10 4 to 15	15 000 to 24 000	11 000 to 15 000	39 000 to 47 000	21 000 to 22 000	19 000	1-3	1-3	95 to 110	2 1200 to 1500	1-2	3-5	270	5 (140°C)	1 0.3 to 0.6	3 depends on resins used	4
Melamine	(GB-128M) G-	5 350 to 520	5 320 to 380	10 50	8 11.0 to 1.40	8 6.9 to 7.7	8 .094 to .12	2 185 to 125	25 000 to 37 000	22 000 to 33 000	30 000 to 97 000	40 000 to 53 000	38 000 to 45 000	1-3	1-3	120	3 900 to 1750	5-8	6-8	270	3 (160°C)	1 0.45 to 0.9	3-7	3-5
Polyester		600	540			2.0	.05 to .03	15-90	20 000 to 35 000		20 000 to 23 000	37 900 to 40 000				110 to 114		6-8	6-8					
Silicone	Continuous filament	10 250 to 300	10 50 to 250	10 3000	1 1.2 to 1.7	1 2.8 to 4.3	1 .0048	1 228	8 19 000	8 17 000	35 000 to 75 000	32 000 to 44 000	30 000 to 37 000	2-5 2.7	2-5	100	5 900 to 1100	1-4	1-2	260	1 (250°C)	1 0.15 to 0.65	1-7	9-10
Glass Mat Phenolic	GM-4	3 600	3 400	9 175	5 .013	5 3.75	5 .049	10 10	6 6500	6 6200	29 000	6 9000	4 8500	4-6 8	4-6 7.5	.85	1 900	1 1-3	3-5	230	(140°C)	1 0.23	depends on resins used	
Melamine	T36 Type Glass Mat (⅛K)	5 380	5	9 450 70V (after 96 hr at 95% RH) 9	9 .015	8 7.2	8 .11	2 132	6 19 800	6 19 800	18 200 edge-wise	6 32 000	33 000	5-8 7	5-8 7		2 900	5-8	3-5	250	(160°C)	1 2.0 (18 K)	3	3
Polyester*		600	540			2.0	.05 to .07	90	19 000 (93°C)		3900 (93°C)	1300 (93°C)						6-8	6-8					
Silicone		9	9	9	1	1	1	1	7	7	7	7	7	4	4		3	1-4	1		(250°C)	1	1	10
Nylon Cloth Phenolic	MEC-1	5 475	5 375	1 30 000	2 14.0 to 30.0	2 3.5 to 3.9	2 .105	10 15	7 9500	7 3400	5 31 000 to 35 000	6 32 000	6 21 000	1 3	1 5	10	2 700	3 1-2	3-5		(120°C)	1 0.2 to 0.35	3	4
Melamine	MEC-2	450	250	200	.07	3.9	.273	70	14 000	13 000	4000	27 000	24 000	2.5	3	110	500	6-8	6-8			2.0		
Asbestos Paper Phenolic*	A	5 100 to 200	5 60 to 220	7	.115 to .12	5.2 to 7.5	.6 to 1.12	10 4	7 11 000 to 13 000	8 7000 to 10 000	5 36 000 to 41 000	7 18 000 to 25 000	8 16 000 to 18 000	6	7-8	100 to 110	6 900	1	2	2-5 230	2-5	3 0.4 to 2.0	3	4
Melamine	MA	100 to 150	60 to 80	5	.11 to .22	8.0 to 9.6	9	.80	10 000	6000	27 000 to 47 000	17 000	13 000	6-7	8	115	900	3	3	230	2-3	5 1.0 to 4.2	2	1
Polyester		5	5	5				3	7	8	5	7	8	6			6	3	3	2-3	1-3	2		
Silicone		10	10	10				3	9	10	5	9	10	7	8		7	2	1	1-3	2-5	3 0.3 to 3.0	3	4
Asbestos Cloth Phenolic	AA	7 60 to 150	7 45 to 125	9	.15 to .44	6.6 to 7.5	1.12 to 2.99	10 4	6 10 000 to 12 000	7 6500 to 11 000	5 18 000 to 49 000	6 19 000 to 25 000	7 15 000 to 24 000	4-6	4-7	106 to 110	5 1100 to 1800	1	2	2-5 270	2-3	3-6	2	1
Melamine		7 40 to 100	7	9				4	6 9000 to 12 000	7	5 25 000 to 50 000	6 20 000 to 24 000	7	6	7	110 to 115	5	3 3	3 3	2-3				
Polyester		600	540			2.0	.05 to .03	90	7100		18 500	31 000				102						0.56		
Silicone		10 50 to 150	10 50 to 100	10				4	8	9	5 40 000 to 50 000	8 12 000 to 16 000	9	7	8		6	2	1	1-3	1-2	3 1.0 to 1.5	3	4
Asbestos Felt Phenolic	FA-72	70	50					4	21 000	17 000	16 000 to 52 000	38 000	27 000	4	6	115	1400	1	2	225		0.4 to 1.0	3	4
Melamine																		3	3					
Polyester*																		3	3					
Silicone																		2	1					

[illegible] used for comparison basis

Phenolic*	A	5 100 to 200	5 60 to 220	7	.115 to .12	5.2 to 7.5	.6 to 1.12	10 4	7 11 000 to 13 000	8 7000 to 10 000	5 36 000 to 41 000	7 18 000 to 25 000	8 16 000 to 18 000	6	7-8	100 to 110	6 900	1	2	2-5 230	2-5	3 0.4 to 2.0	3	4
Melamine	MA	100 to 150	60 to 80	5	.11 to .22	8.0 to 9.6	9	.80	10 000	6000	27 000 to 47 000	17 000	13 000	6-7	8	115	900	3	3	230	2-3	5 1.0 to 4.2	2	1
Polyester		5	5	5				3	7	8	5	7	8	6			6	3	3	2-3	1-3	2		
Silicone		10	10	10				3	9	10	5	9	10	7	8		7	2	1	1-3	2-5	3 0.3 to 3.0	3	4
Asbestos Cloth Phenolic	AA	7 60 to 150	7 45 to 125	9	.15 to .44	6.6 to 7.5	1.12 to 2.99	10 4	6 10 000 to 12 000	7 6500 to 11 000	5 18 000 to 49 000	6 19 000 to 25 000	7 15 000 to 24 000	4-6	4-7	106 to 110	5 1100 to 1800	1	2	2-5 270	2-3	3-6	2	1
Melamine		7 40 to 100	7	9				4	6 9000 to 12 000	7	5 25 000 to 50 000	6 20 000 to 24 000	7	6	7	110 to 115	5	3 3	3 3	2-3				
Polyester		600	540			2.0	.05 to .03	90	7100		18 500	31 000				102						0.56		
Silicone		10 50 to 150	10 50 to 100	10				4	8	9	5 40 000 to 50 000	8 12 000 to 16 000	9	7	8		6	2	1	1-3	1-2	3 1.0 to 1.5	3	4
Asbestos Felt Phenolic	FA-72	70	50					4	21 000	17 000	16 000 to 52 000	38 000	27 000	4	6	115	1400	1	2	225		0.4 to 1.0	3	4
Melamine																		3	3					
Polyester*																		3	3					
Silicone																		2	1					

* One of the more commonly used Polyesters was used for comparison basis.

LEAD WIRE (STRANDED CABLE)

Material	General Remarks	Insulation Resistance	Abrasion (resistance to)	Flexure (life under)	Bend (continuity of insulation under)	Stripping	Maximum Operating Temperature	Thermal Aging	Resistance to Moisture	Oil	Acid	Base	Solvent
Plastic or Rubber Plain		2	2	1	1	3	5	3	2	4	2		1
Cotton Braid and Lacquer		4	1	2	2	1	4	4	3	2	3		3
Rayon Braid and Lacquer		3	4	3	3	2	4	4	4	3	4		4
Glass Braid and Lacquer		1	3	4	4	4	3	3	1	1	1		2
Cotton Cambric and Cotton Braid		3	2	3	4	4	4	4	3	4	6		4
Multiple Cotton Braid		6	5	4	3	5	5	10	10	10	10		6
Asbestos Cambric and Outer Braid of Asbestos		4	2	2	4	8	2	2	6	6	6		3
Glass Conventional Varnish, Outer Braid of Asbestos		3	2	2	4	7	2	2	4	5	5		3
Silicone Varnish, Outer Braid of Glass		3	5	6	5	4	1	1	6	5	5		3
Silicone Rubber, Outer Braid of Glass		2	5	6	5	4	1	1	5	4	5		4
Fibrous Wraps Nylon Serve or Braid (conventional varnish, shellac)		5	2	4	4	5	3	3	2	2	4		2
Rayon Serve or Braid (conventional varnish, shellac)		4	4	5	5	6	5	4	5	5	6		3
Glass Serve or Braid (conventional varnish, shellac)		3	3	5	5	5	2	2	2	4	6		3